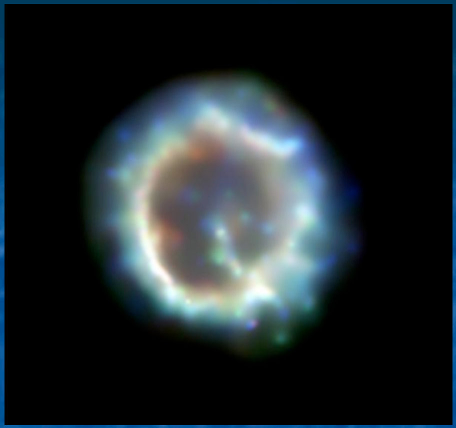
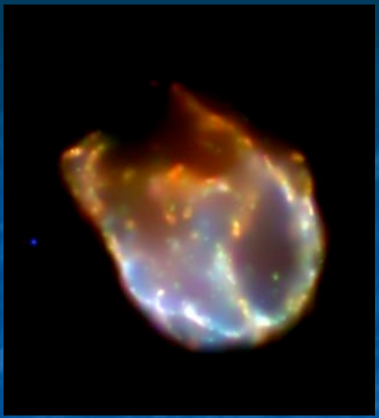
High Resolution Spectroscopy of Supernova Remnants with Chandra, XMM-Newton and Constellation-X

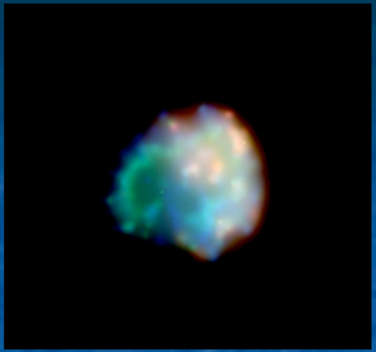
K.A. Flanagan, C.R. Canizares, D. Dewey



E0102-72



N132D

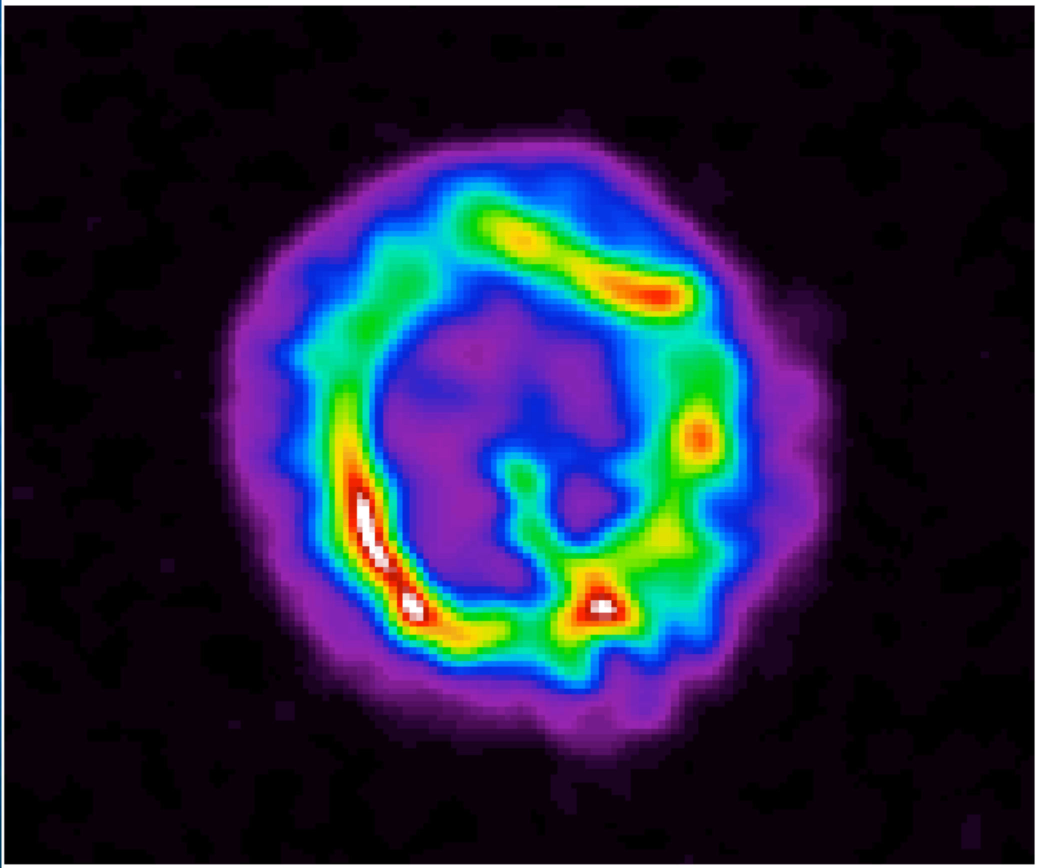


N103B

SN1006

The future with Con-X

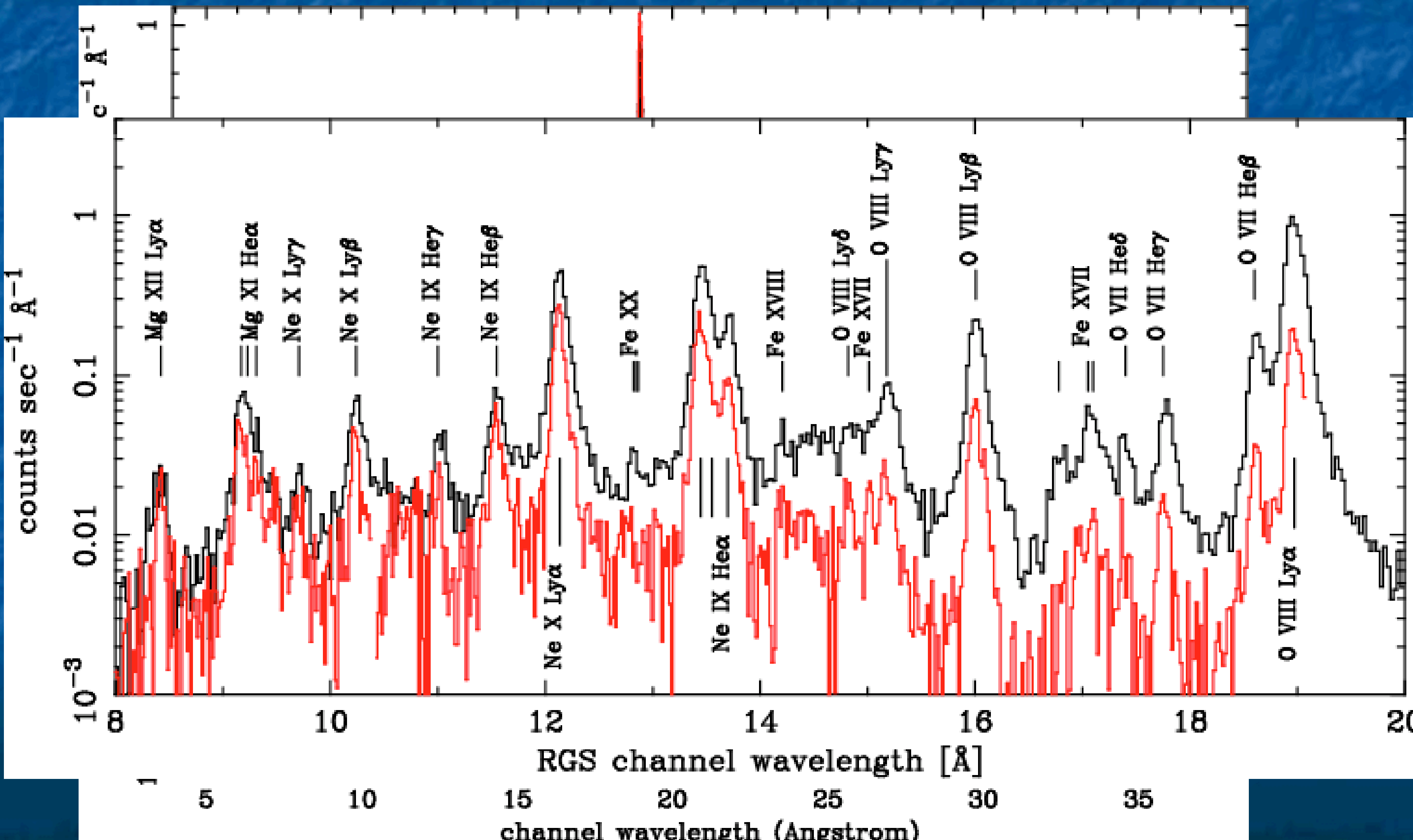
Supernova Remnant: 1E0102-7219



- ~1000 years
- SMC
- Blast wave
- Reverse shock

XMM-Newton Spectrum of E0102-72

Rasmussen, et al. 2001



E0102 and RGS

Rasmussen et al 2001

- Brightest lines are from C,O, Ne and Mg. Weak Fe L
- Plasma diagnostics with emission lines from single ions

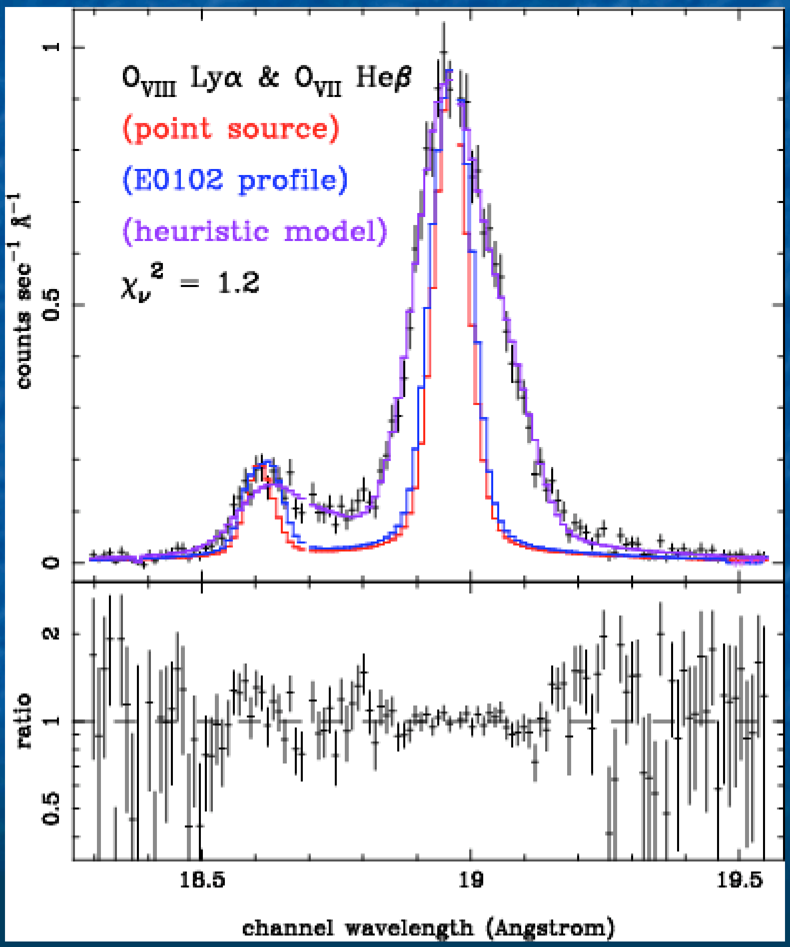
O VII: 0.35 < Te < 0.7 keV

Ne IX: 0.6 < Te < 1.0 keV

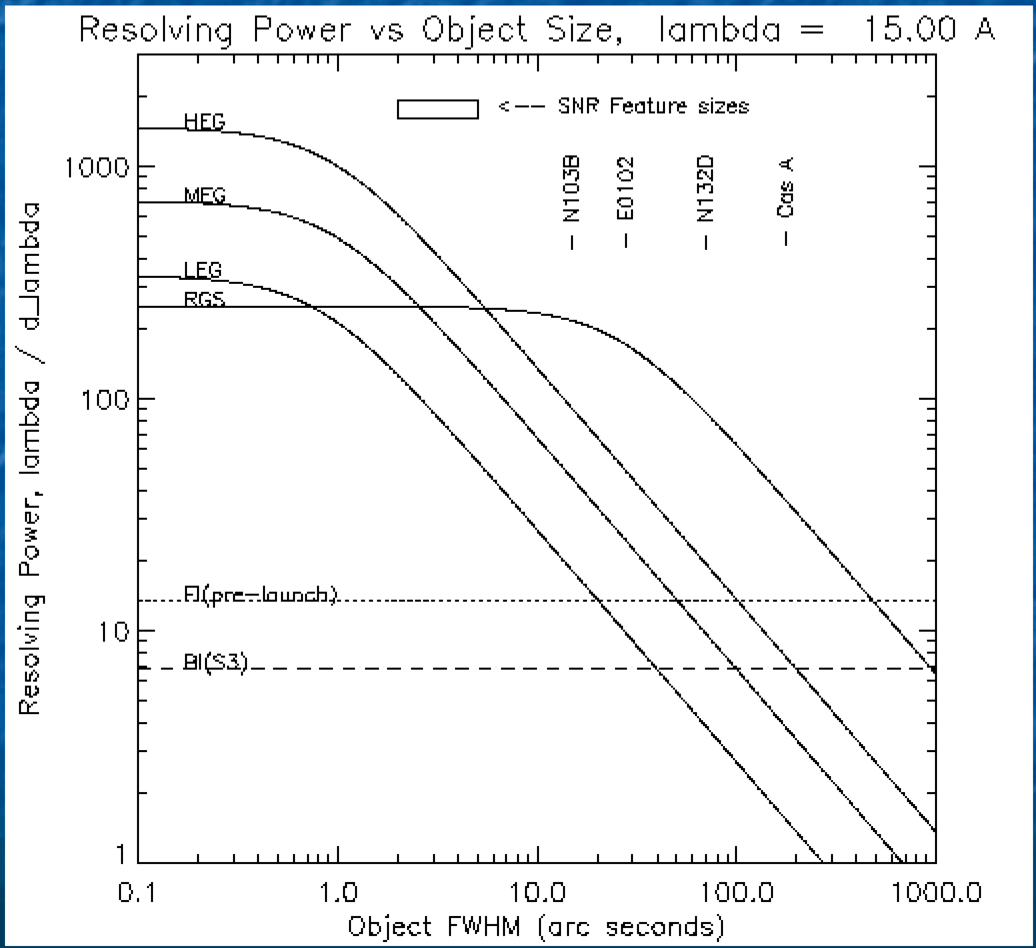
- F, I and R triplet ratios of OVII and Ne IX indicate **ionizing plasma, low density limit** and T_e(NeIX)=0.65 keV, T_e(OVII)=0.35 keV

- Emission line ratios for OVIII are anomalous, and authors consider charge exchange at cloud interfaces

Oxygen line broadness indicates ejecta expansion of v>1350 km/s

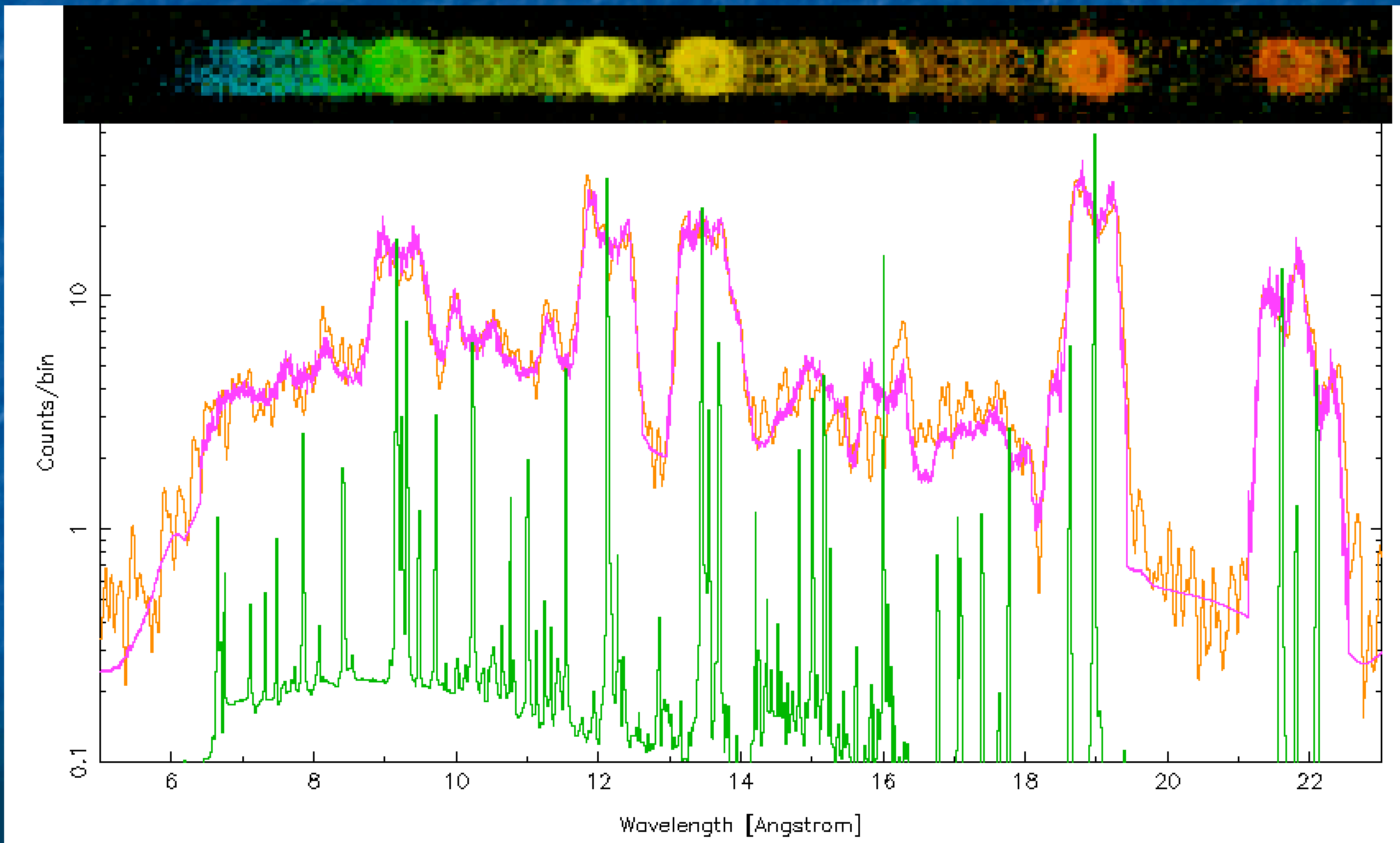


RGS retains its resolving power for moderately extended sources

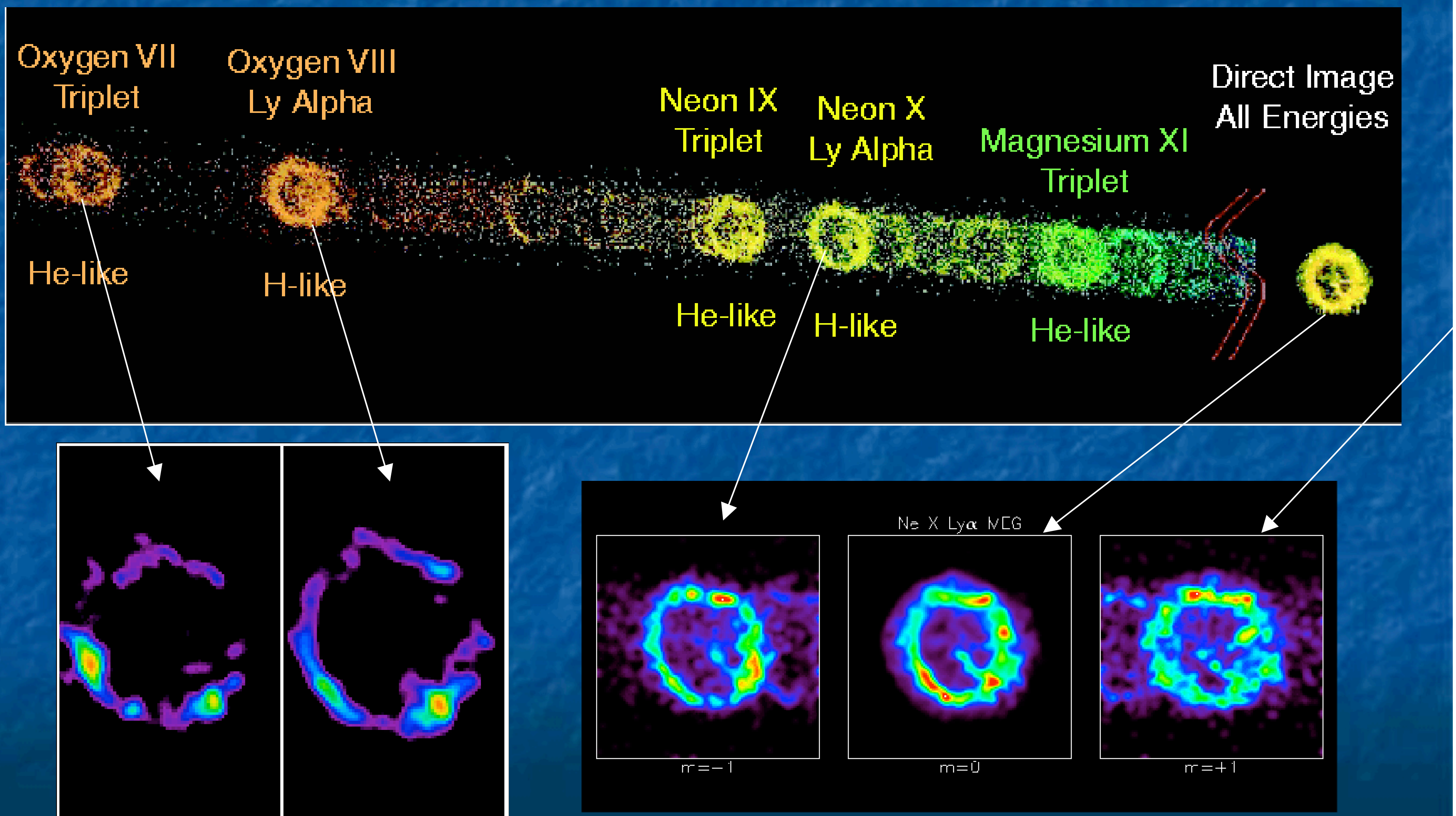


Dewey, 2002

The HETG "histogram" is degraded relative to a point source…but some analysis can *only* be done when the object appears extended!

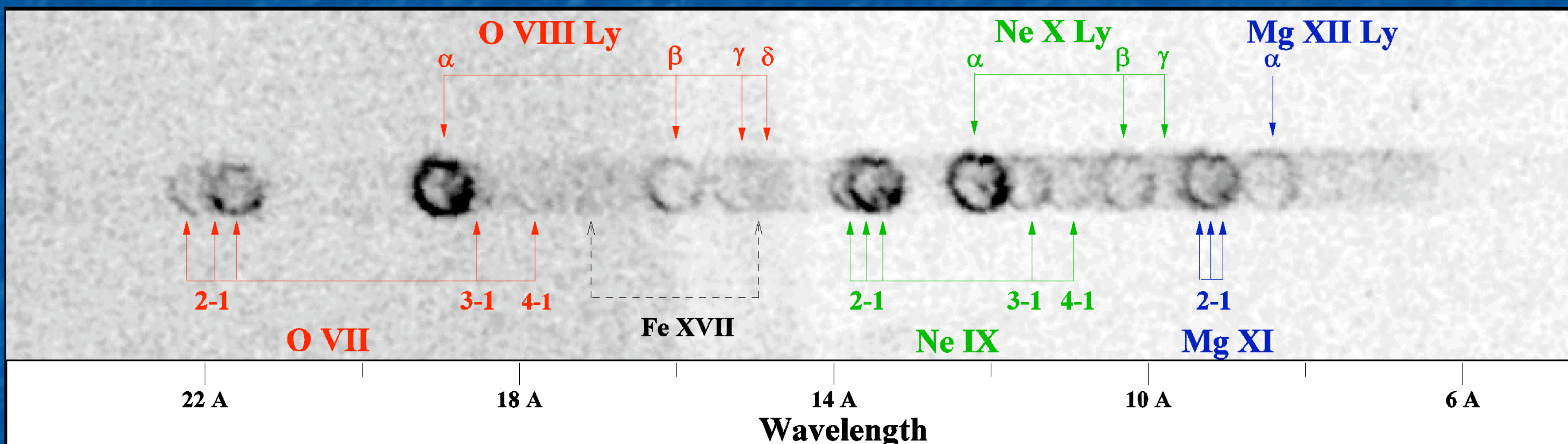


HETGS Spectrum of E0102



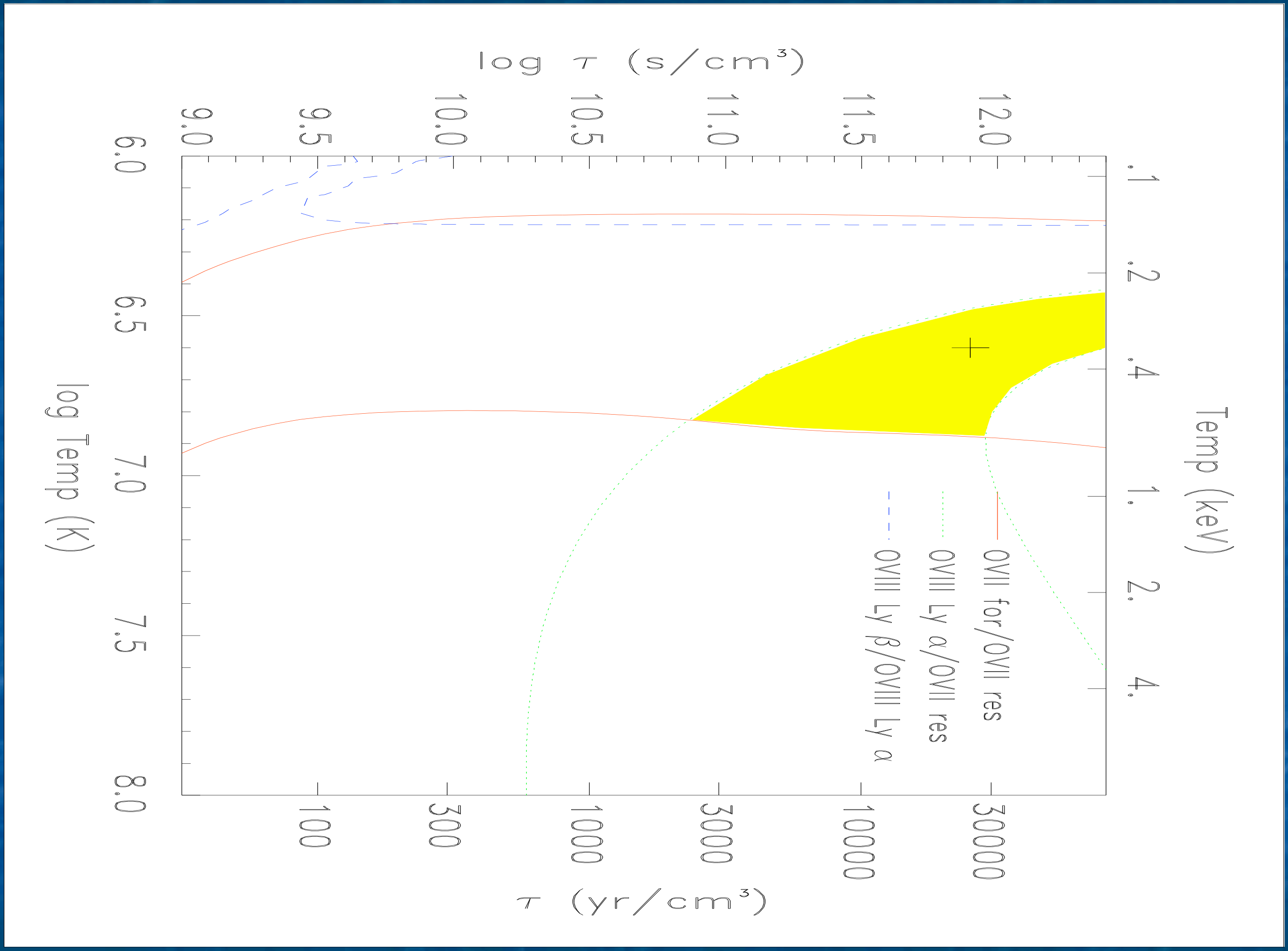
Flanagan et al. 2001,2002

X-ray Lines in E0102-72
H-like and He-like O, Ne, Mg and Si



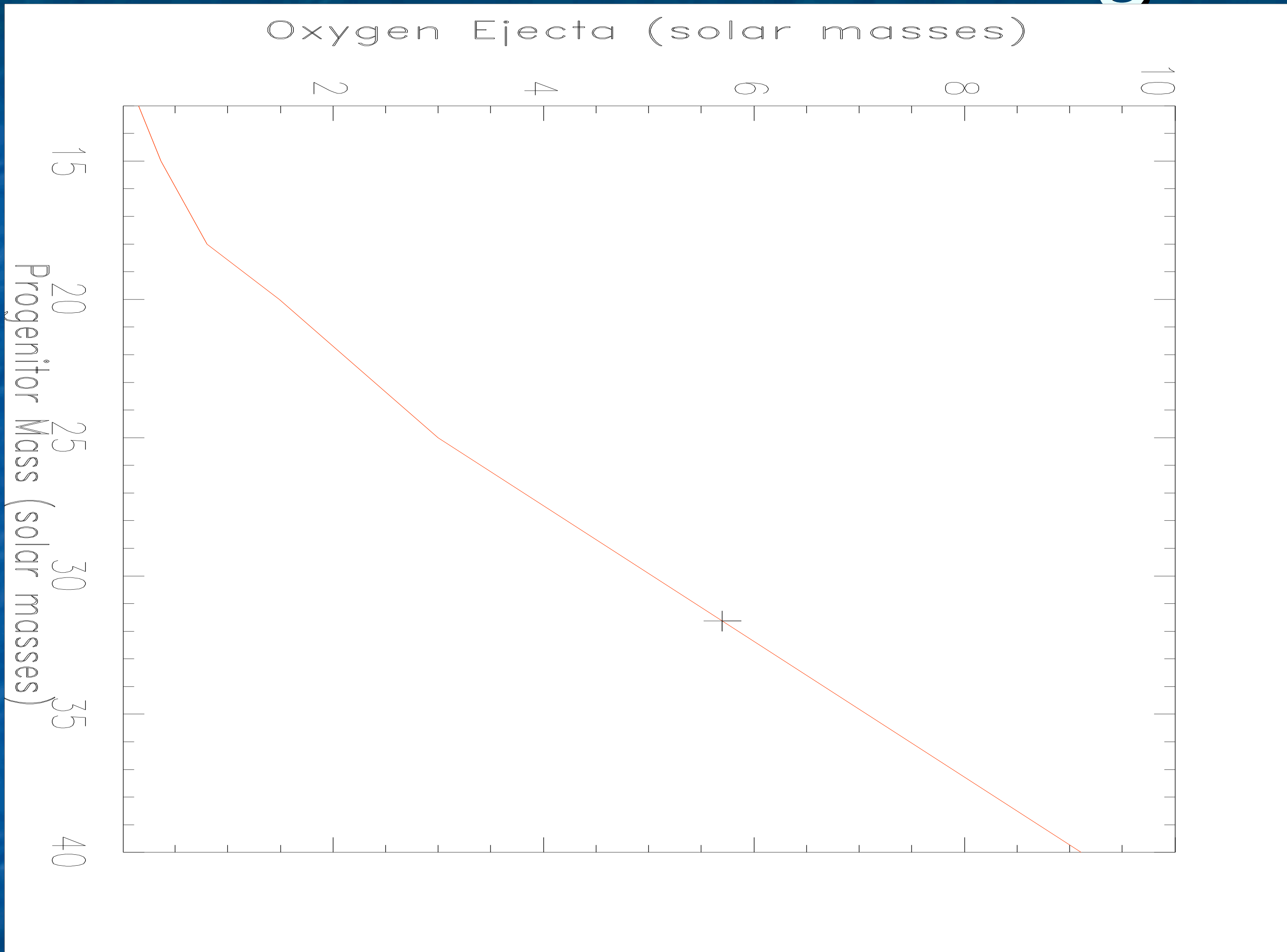
weak Fe

Plasma Diagnostics – oxygen lines



Shock model parameters compatible with measured Ratios. Constraints on temp, ionization age and abundance

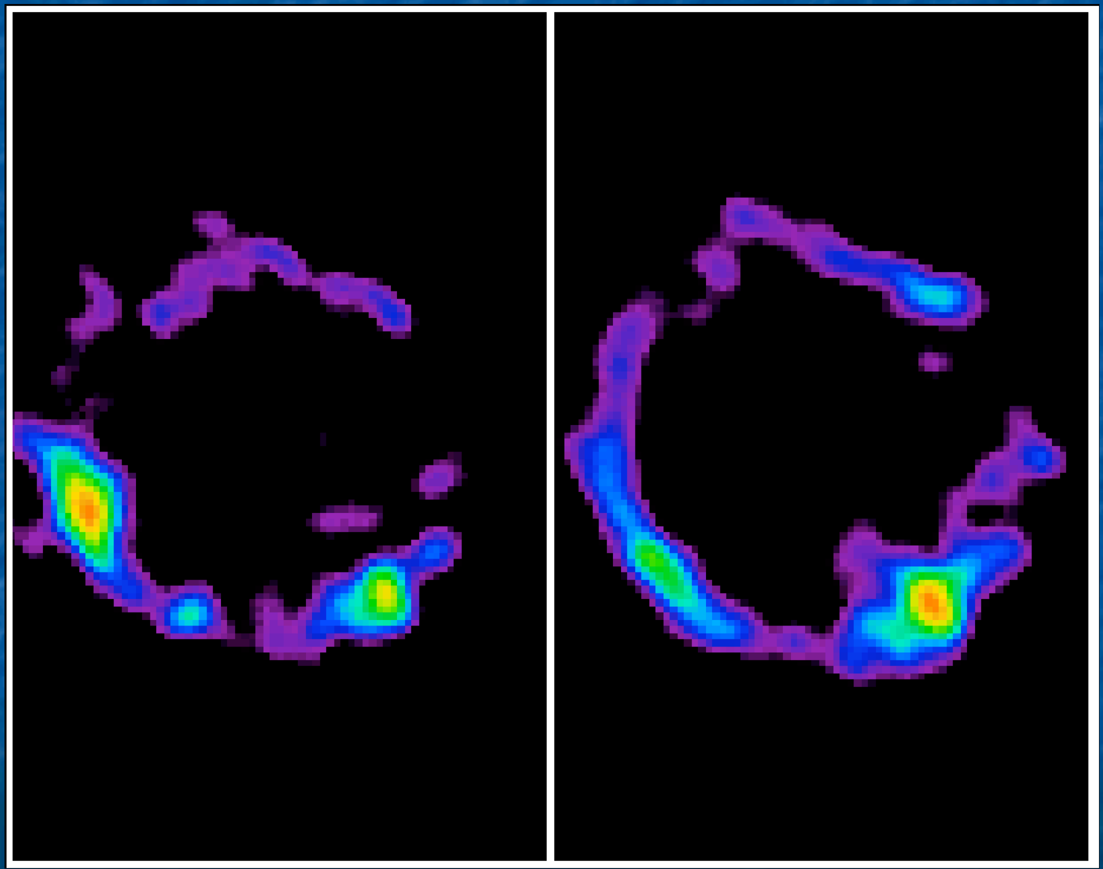
Abundance and Progenitor



Models of Nomoto et al

~5.7 Solar Masses of oxygen assuming pure metal plasma
~ 32 Solar Mass progenitor!

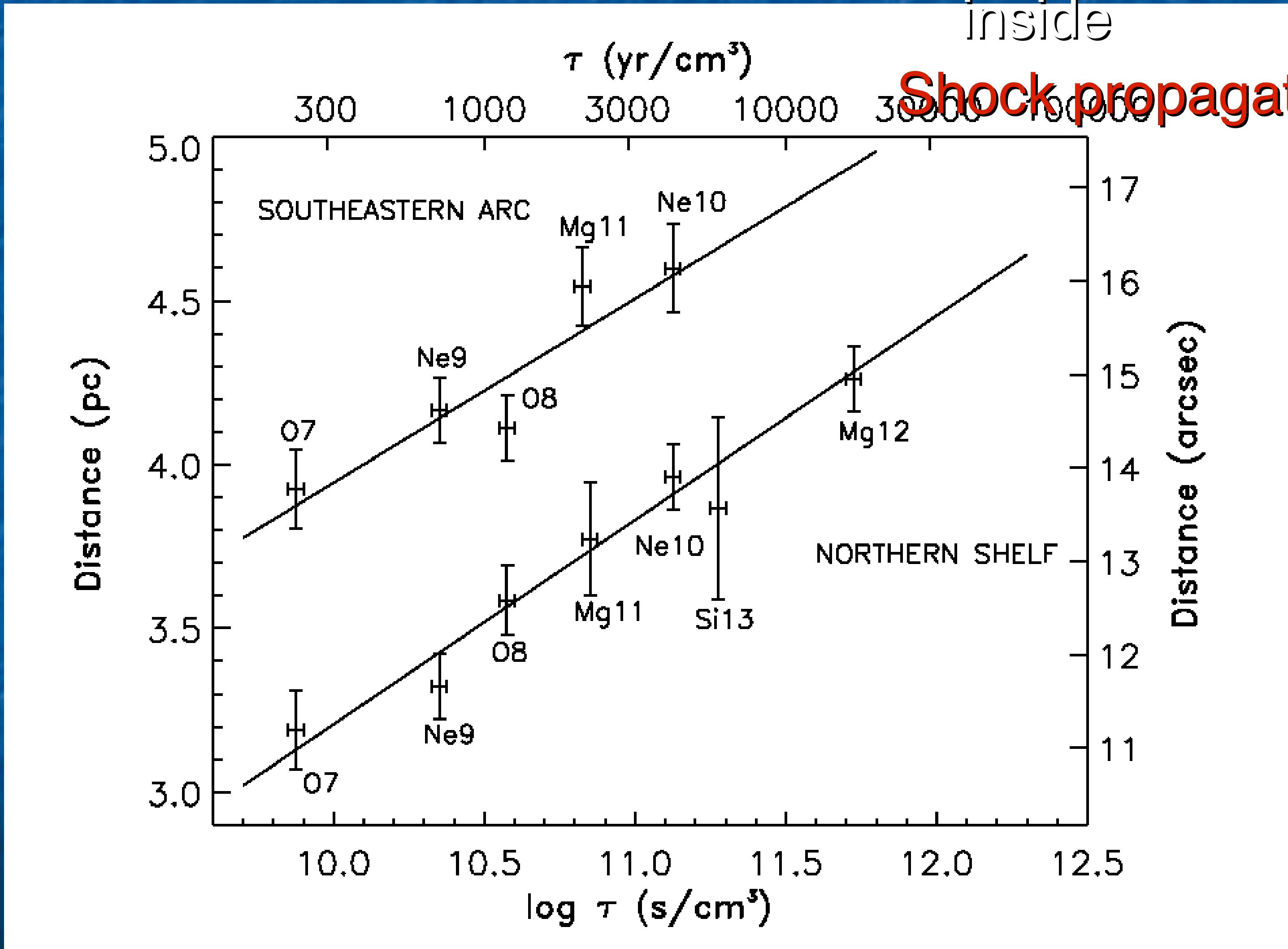
H-like lines lie at larger radius than He-like lines



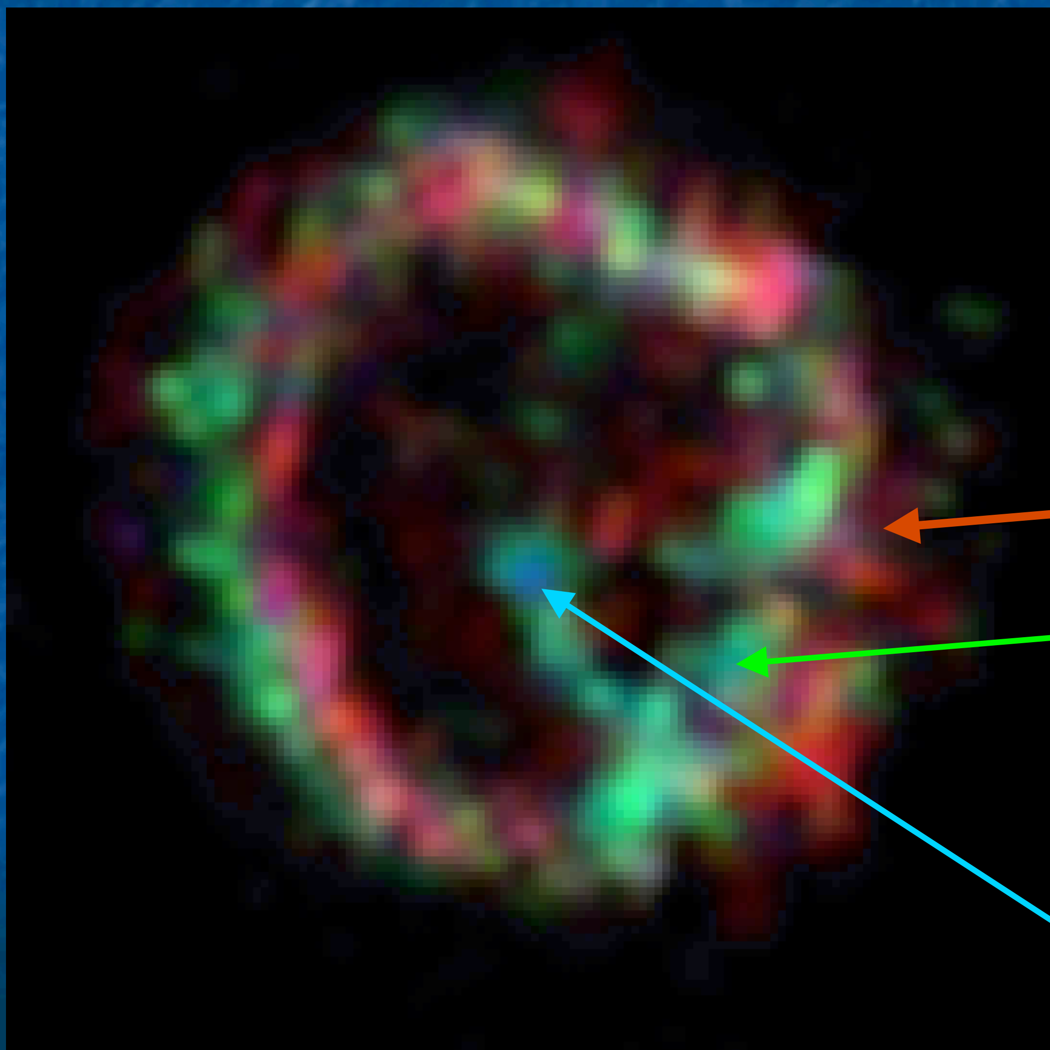
O VII O VIII

Reverse Shock

- Elements intermingled
- More evolved plasma outside
- Less evolved plasma inside
- Shock propagates inward



2-Dimensional Doppler Map of E0102



See D. Dewey's Talk (next)

+900, +1800 km/s

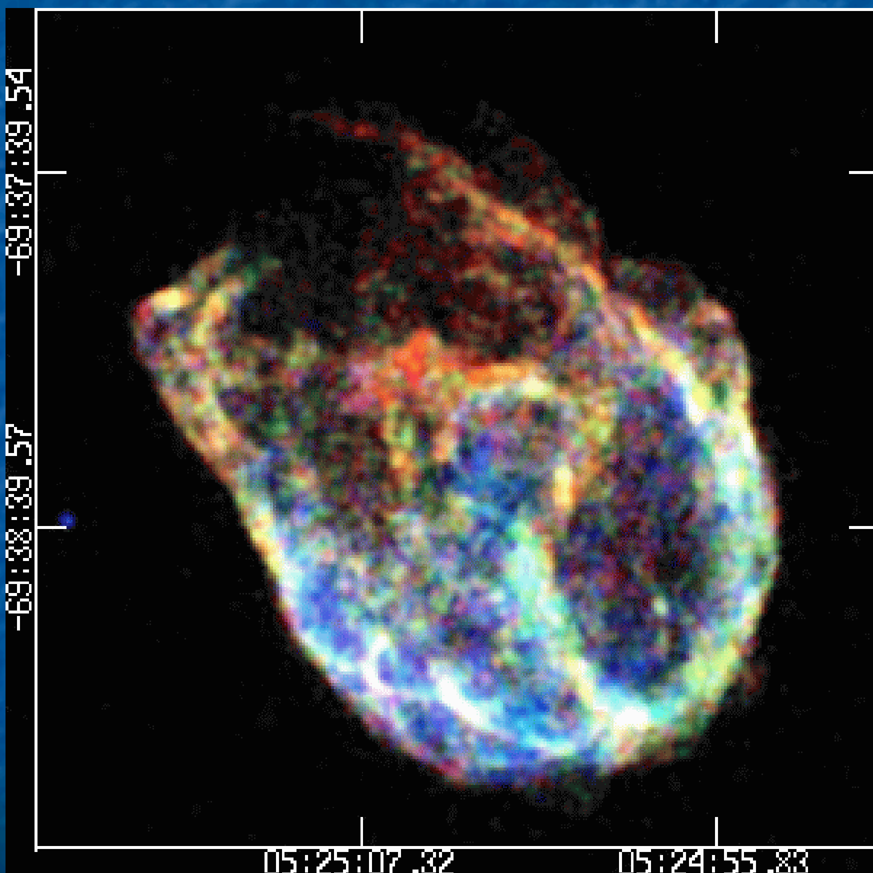
-900 km/s

-1800 km/s

Highlights

- **E0102-**
- Reverse shock
- Plasma diagnostics (temperature, ionization age and abundance)
- Progenitor mass
- Doppler map + 3D modeling

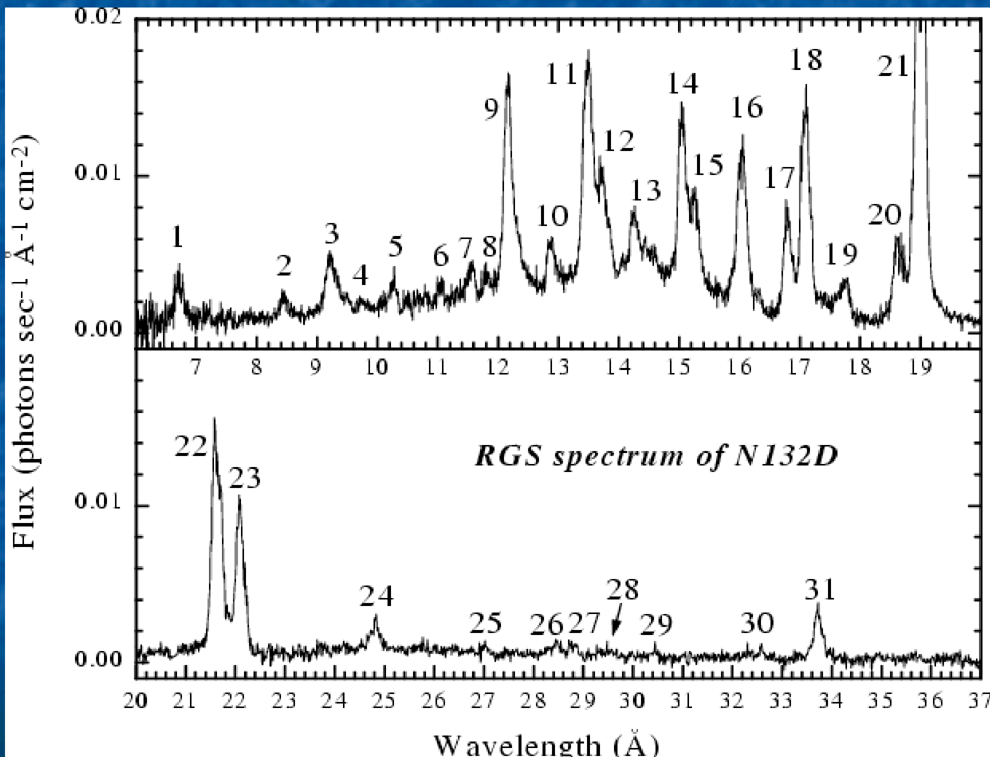
Supernova Remnant: N132D



- **1300 - 3000 years old**
- **LMC**
- **~120”**

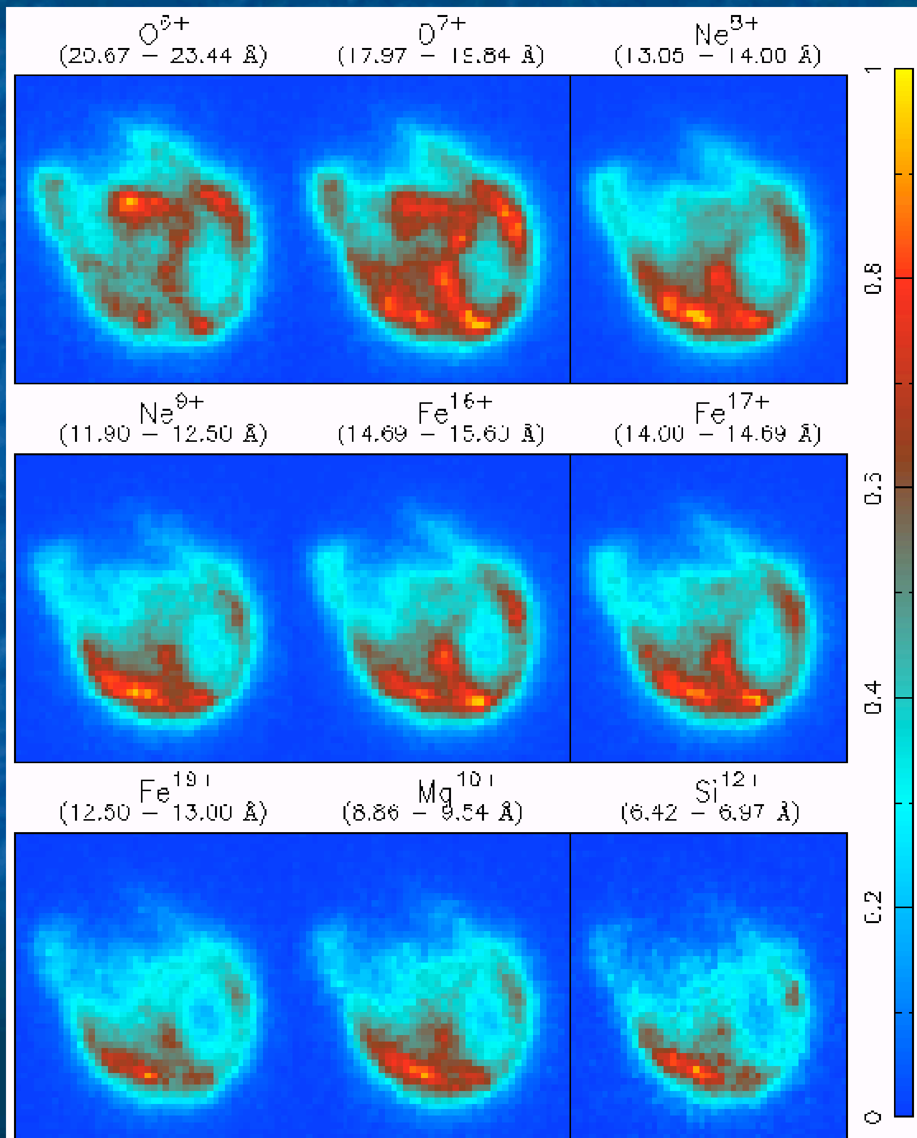
XMM-Newton Spectrum of N132D

- **Behar, et al. 2002**



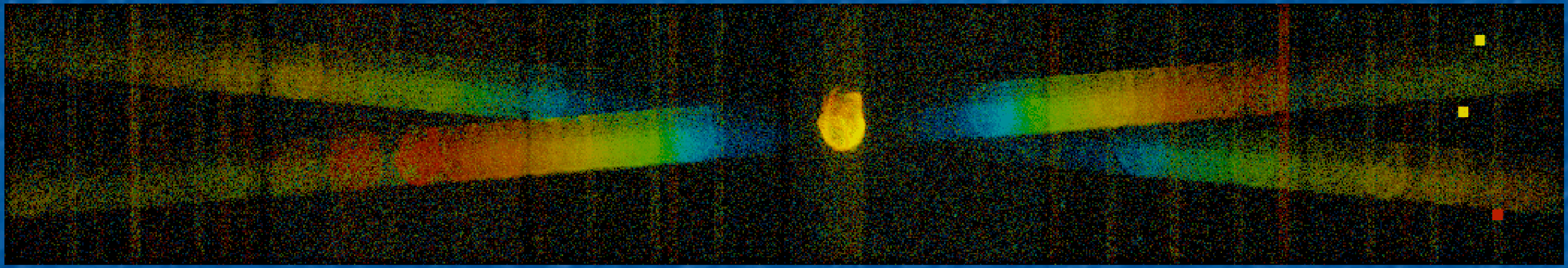
- C, N, O, Ne, Mg, Si, S, Fe
- Fe in CIE over 0.2-1 keV
- O triplet F:I:R=0.62:0.12:1.0 (R> F, ruling out a cooling plasma)
- K-shell Ar, Ca and Fe also seen in EPIC-PN

EPIC-MOS Images



- Except for O, dominant emission is from shocked ISM along SE, NW edge
- Most highly ionized in SE
- Less ionized also occurs in NW
- Oxygen at center – maybe ejecta?
- Bright oxygen knot
- Fe-K seen near center in EPIC-PN images

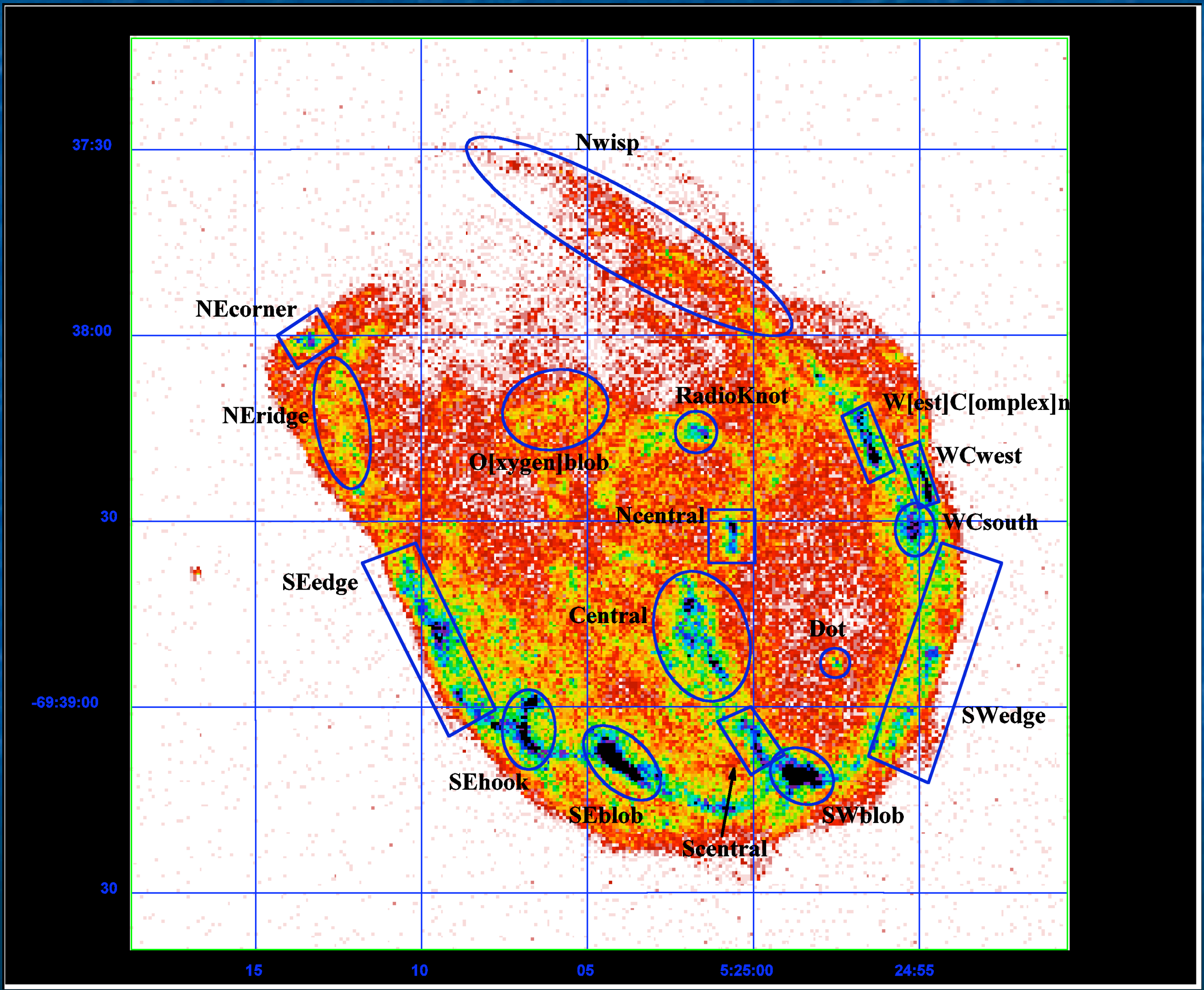
Chandra HETG spectrum of N132D



The source is more extended than E0102-72, and the spectrum is complicated by Fe L. But it spatially distinct high resolution spectroscopy is possible…

HETG spectrum of bright knots and filaments

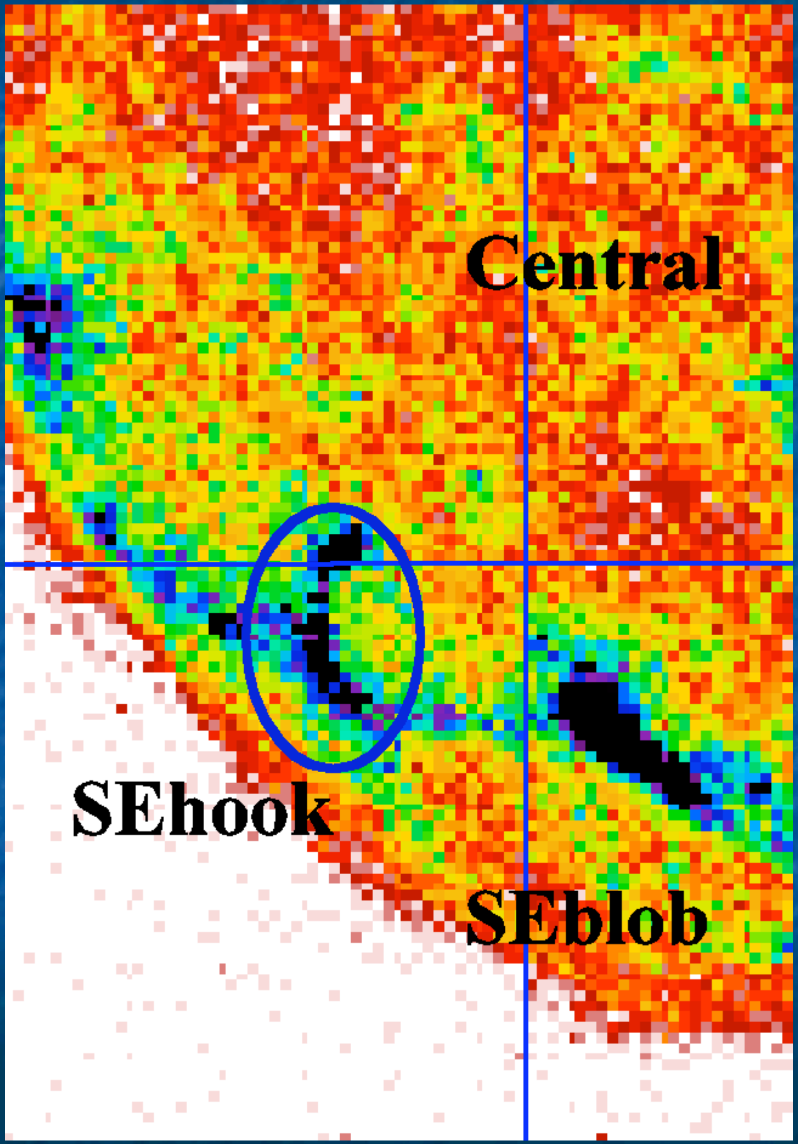
See poster “Plasma Diagnostics of Knots and Filaments of SNR N132D”, poster by Fredericks et al., this conference

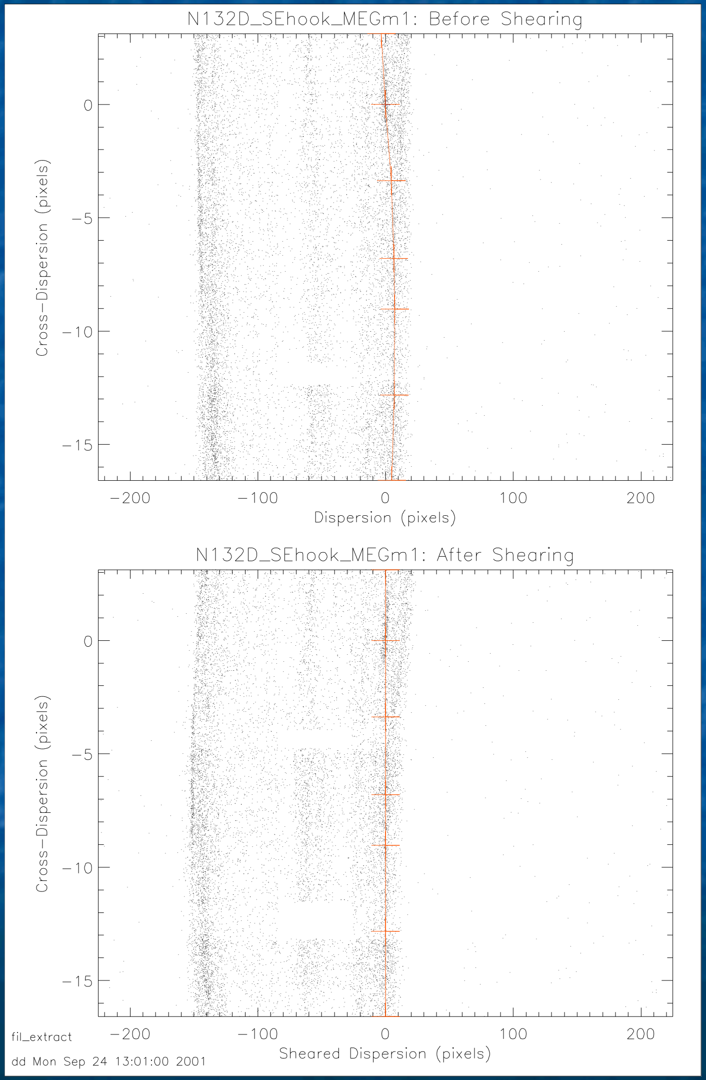


Spectral extraction technique developed by D. Dewey

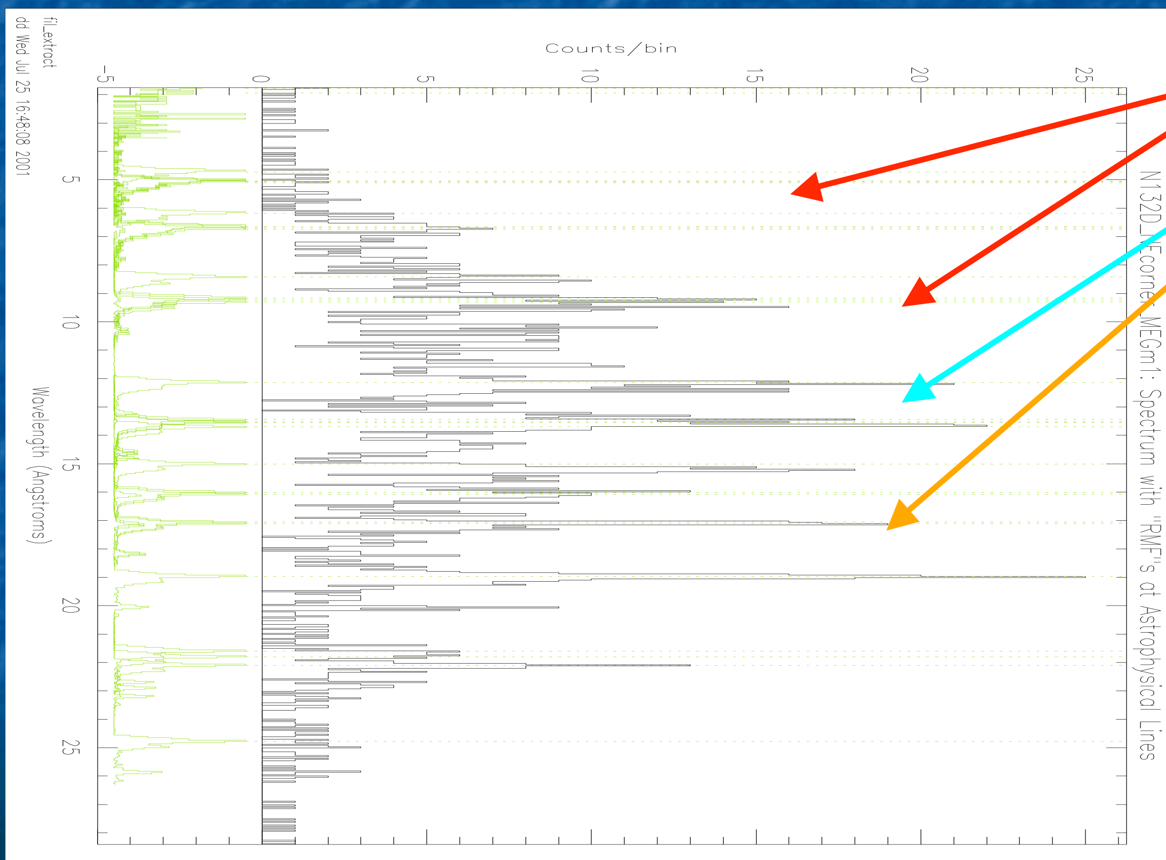
We will look at NE corner, S Central, and O blob

Define a filament path, and align (shear) the elements to narrow the feature and enhance S/N

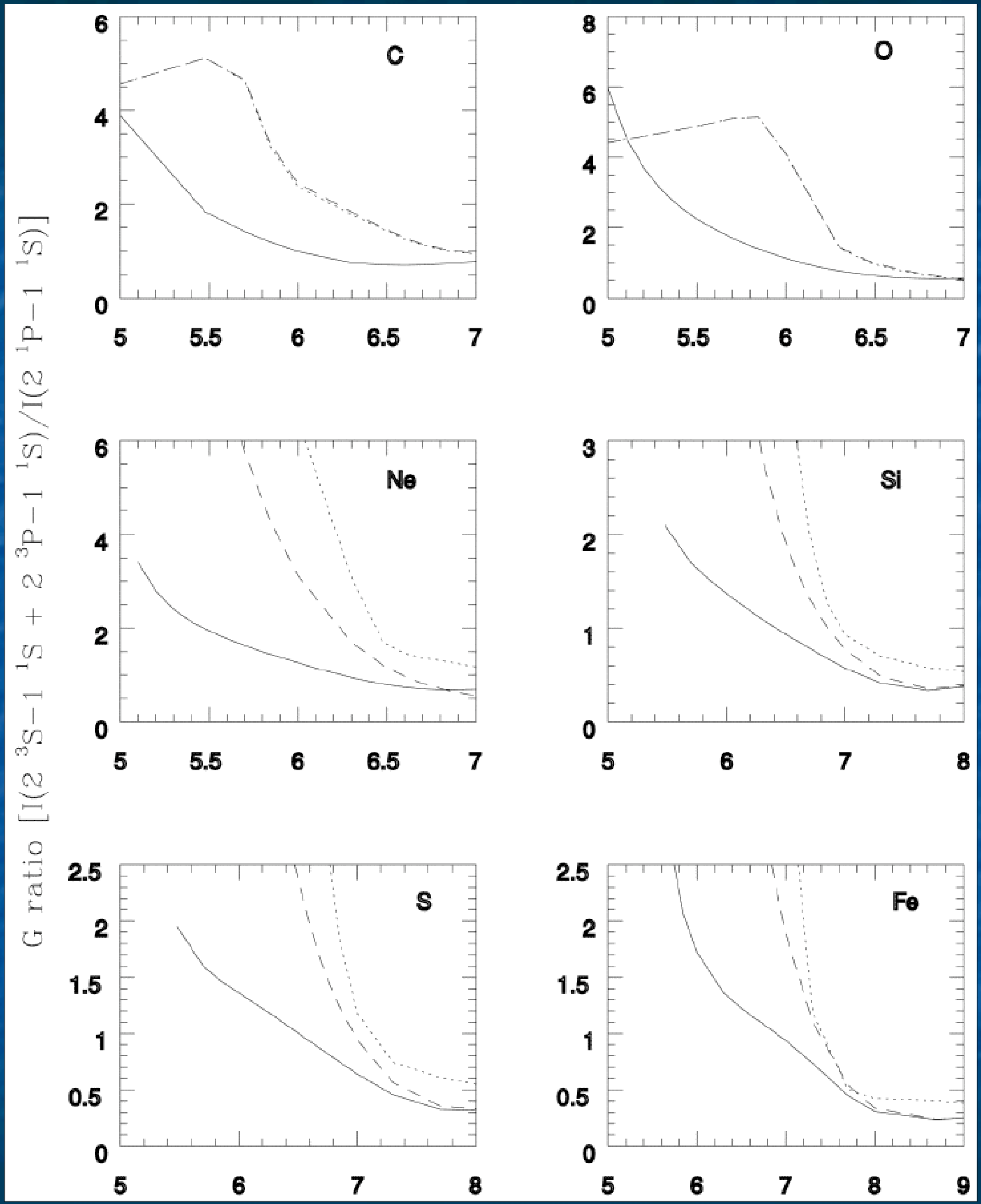




HETG spectrum: N132D NE Corner



- O prominent
- F >> R in oxygen ! Differs from XMM global ratio (F ~ R)
- Implied oxygen plasma conditions TBD



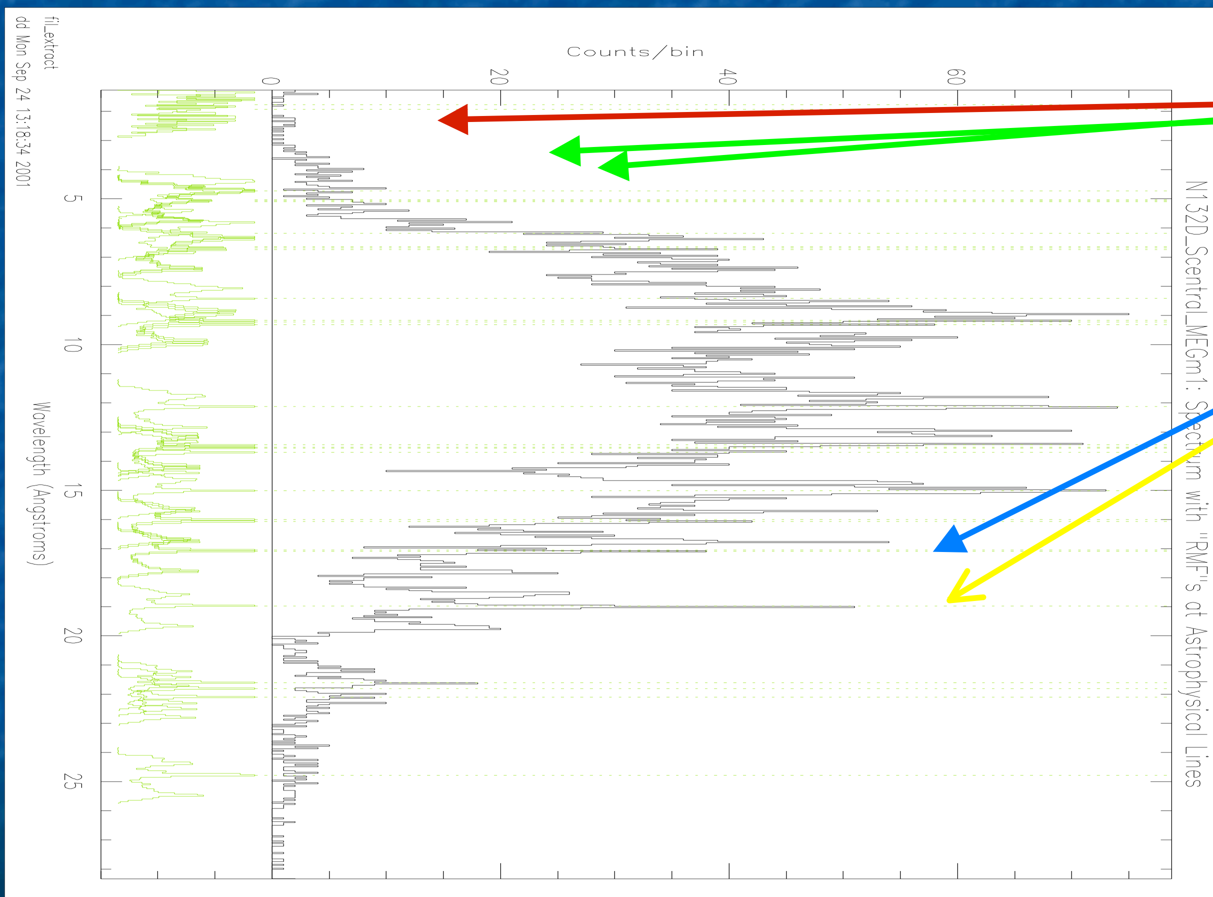
(F+I)/R vs temp

I~.25F

Bautista & Kallman, 2000

Dashed-satellite line contributions included

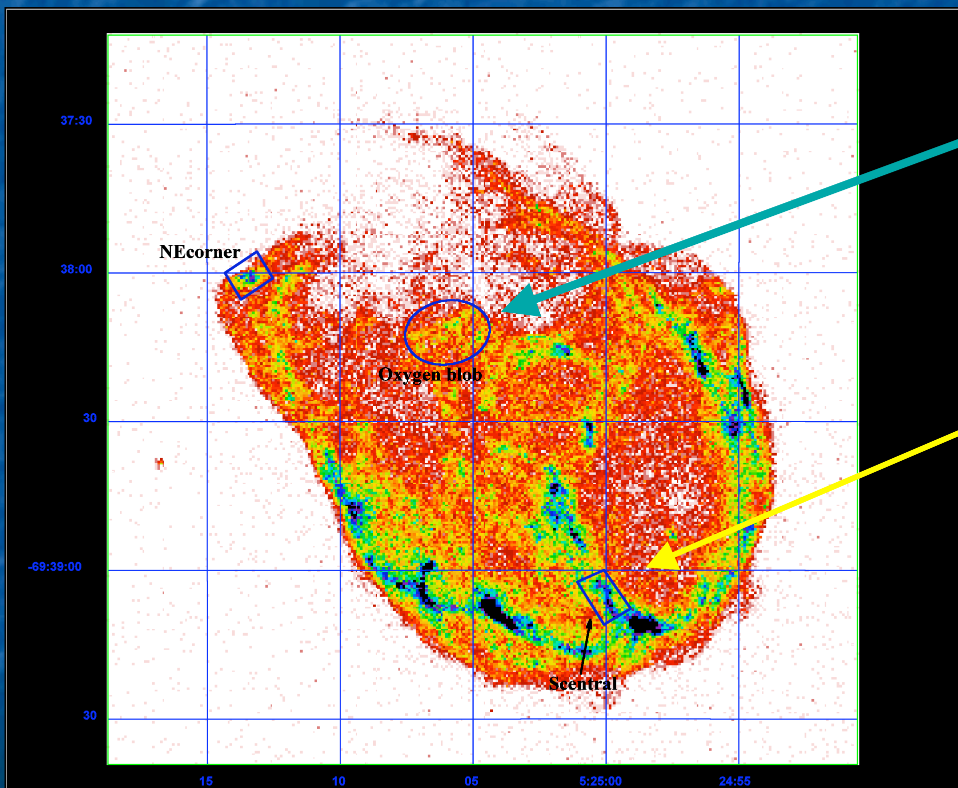
HETG spectrum: N132D S central



- Mg, Ne more prominent than oxygen
- R>F in oxygen
- For oxygen plasma:
- T= 0.68 keV
- $\tau = 1.9\text{X}10^{11}$ s/cm^3

Oxygen “blob”

- Oxygen is dominant, noted by XMM (Behar et al)
- HETG plasma diagnostics tell us specific conditions:

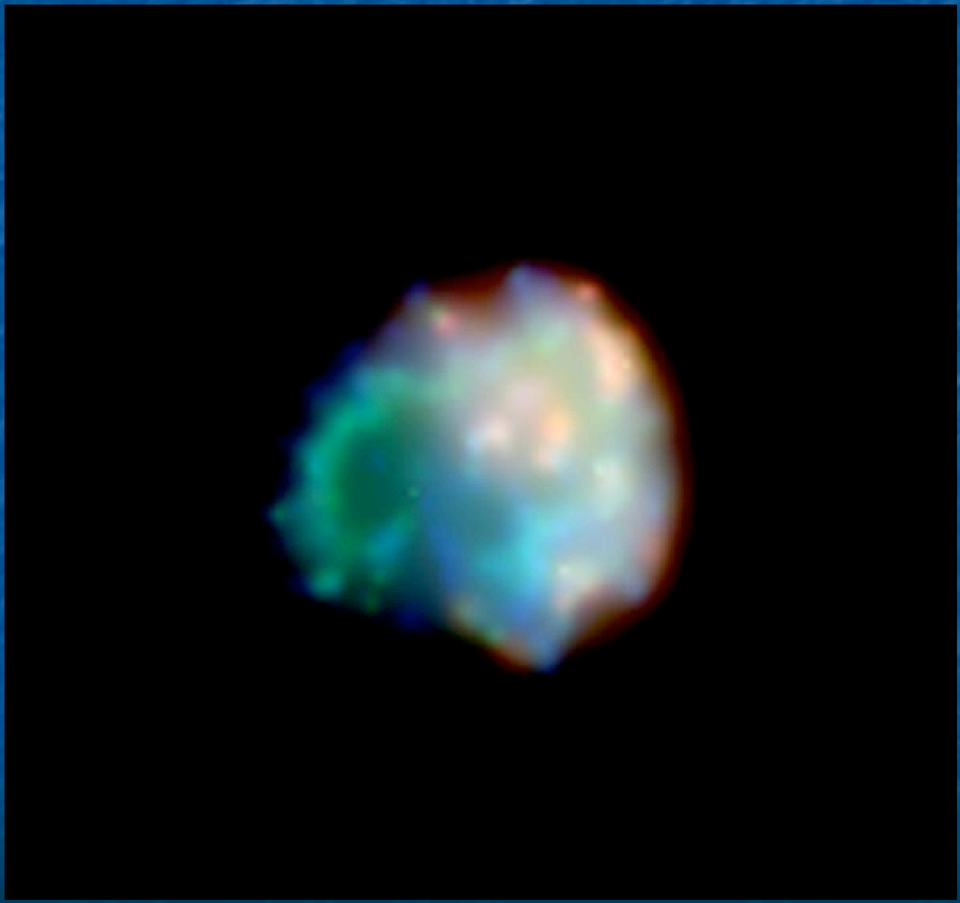


T= 0.24 keV
t = $1.8\text{X}10^{12}$ s/cm3

T= 0.68 keV
t = $1.9\text{X}10^{11}$ s/cm3

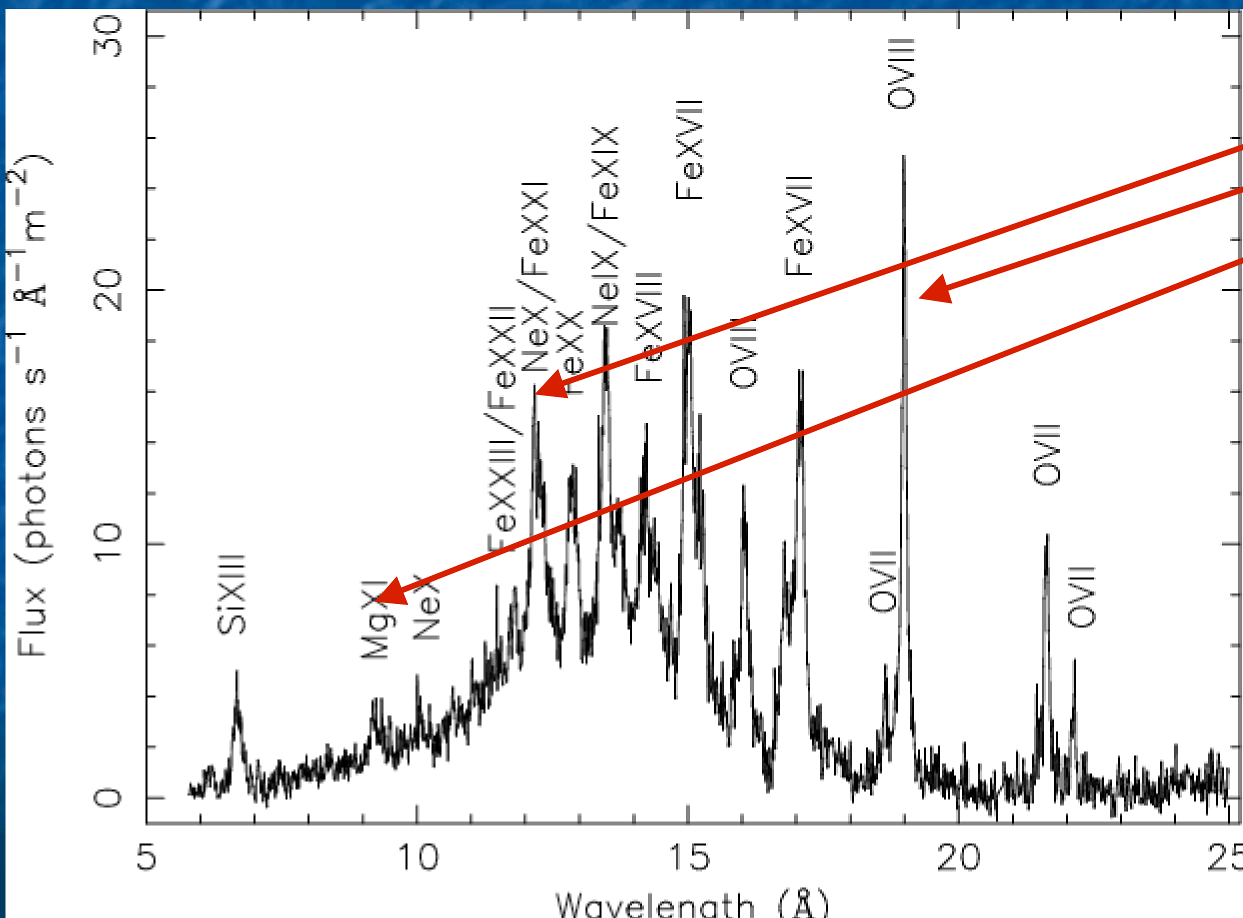
Reasonably good agreement between RGS and HETG for O triplet:
F:I:R=0.62:0.12:1.0 from RGS
F:I:R=0.79:0.13:1.0 from HETG sum of filamentary spectra

Supernova Remnant: N103B



- ~1500 years
- SNR 0509-69
- 4th brightest in LMC
- ASCA showed Si, S, Ar, Ca and Fe but no O, Ne and Mg – so believed Type Ia (Hughes 1995)

RGS Spectrum of N103B
Van der Heyden et al (2002)



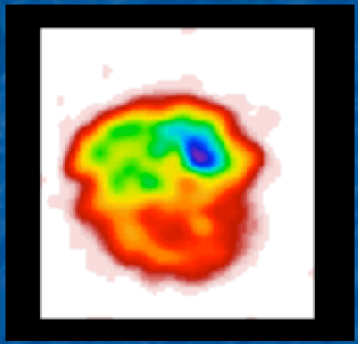
Detects O, Ne, Mg

Opens the question – Could it be core-collapse?

RGS supports type II

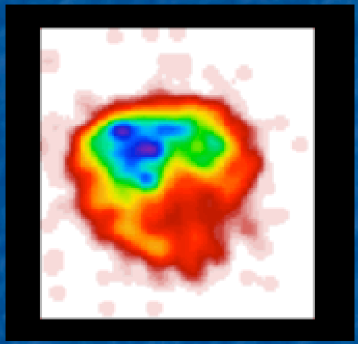
- RGS abundance ratios (relative to Si) do not compare well with LMC. Absolute abundances are larger, suggesting ejecta
- Ratios compare better to type II than type Ia: O/Si, Ne/Si and Mg/Si are larger and Fe/Si lower than for type Ia

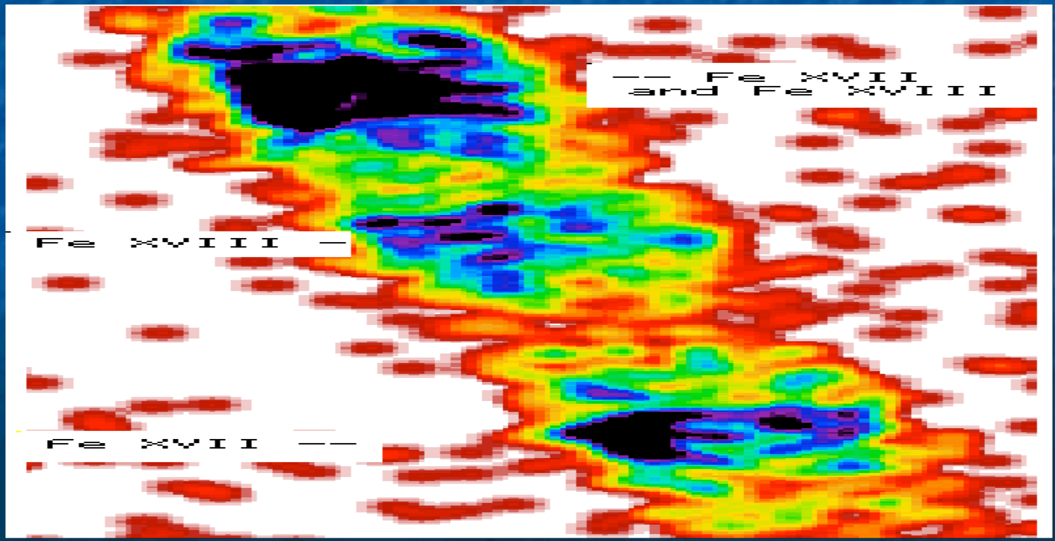
Chandra HETG zeroth order and dispersed images show substructure



Ne X

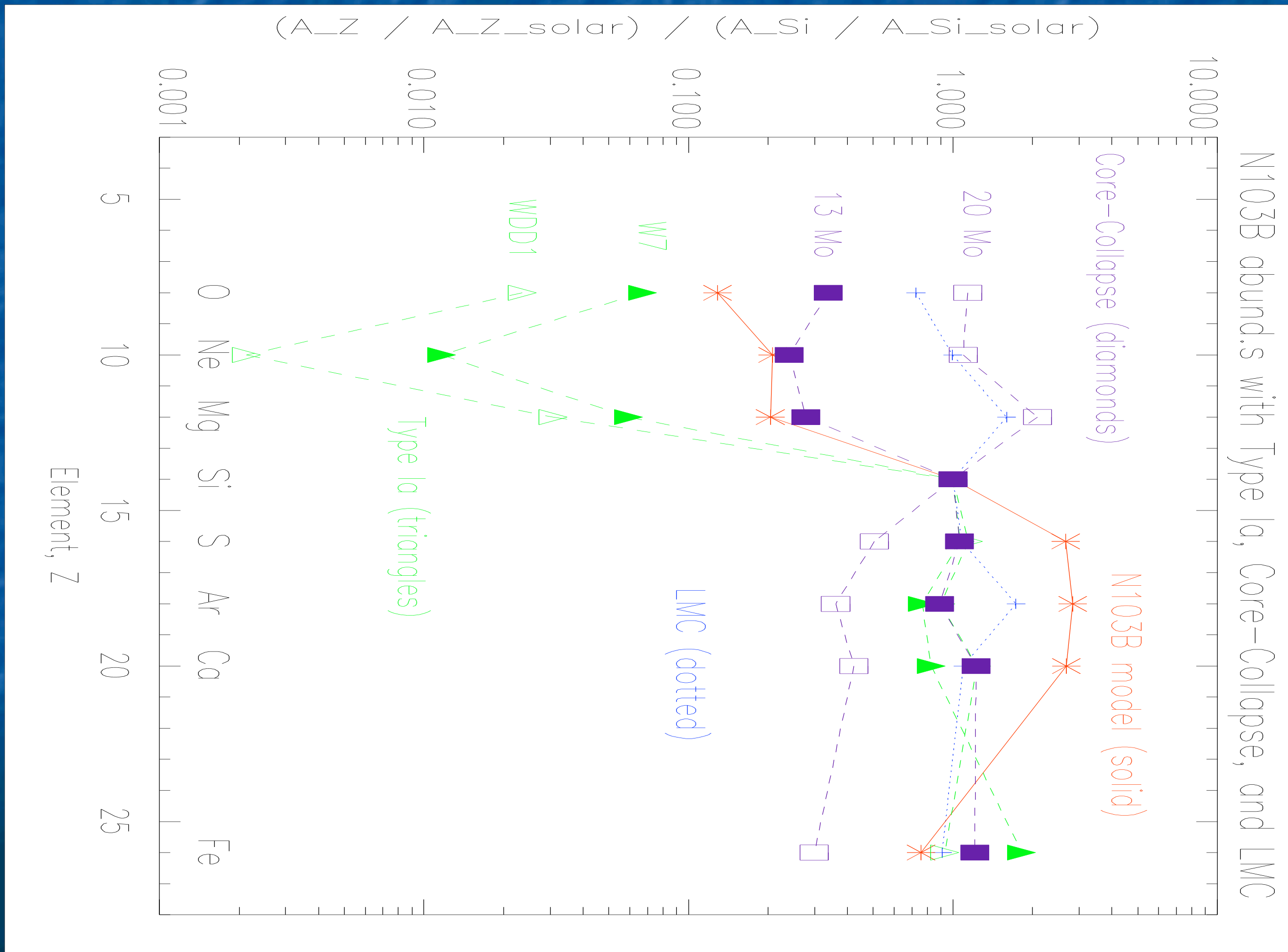
O VIII





Maximum elemental abundances consistent with HETG spectra

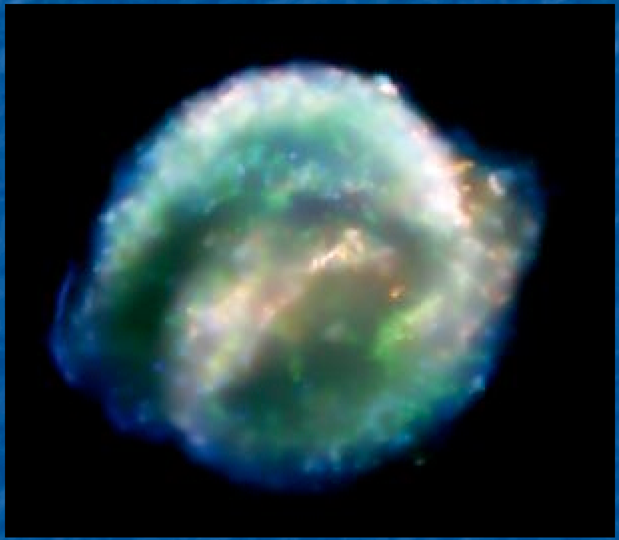
J. Migliozzi thesis (2003)



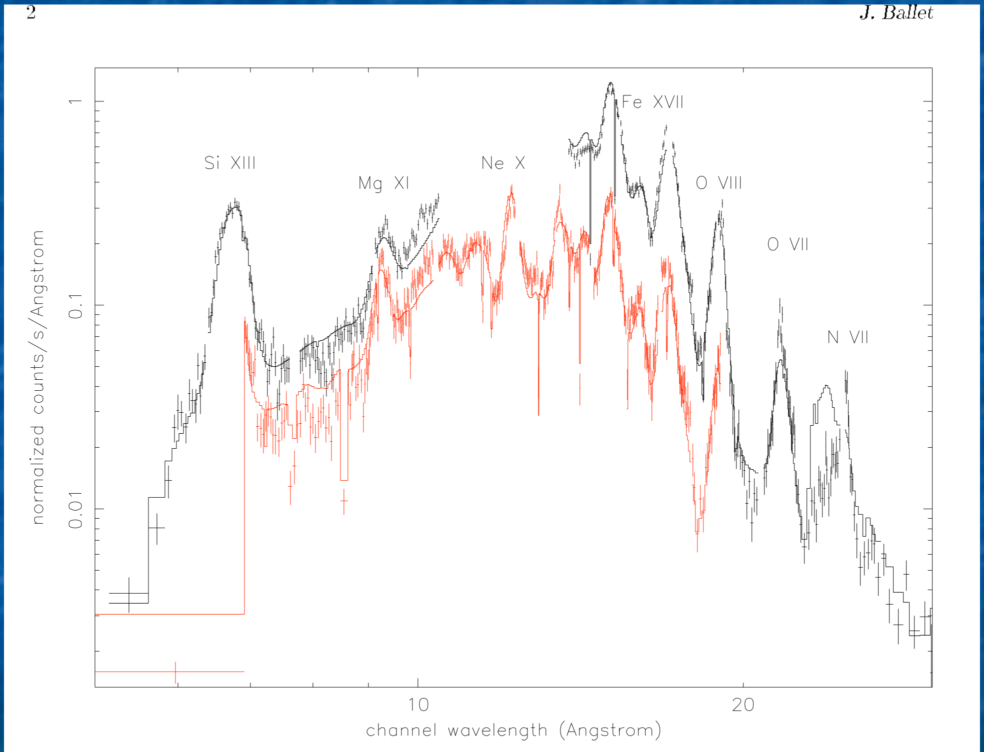
Planar shock models fit well, but derived abundances don't permit definite progenitor classification

Kepler with XMM-Newton RGS

Ballet (2002)



Chandra image - Kepler (SN 1604) is ~200" across at ~5kpc.

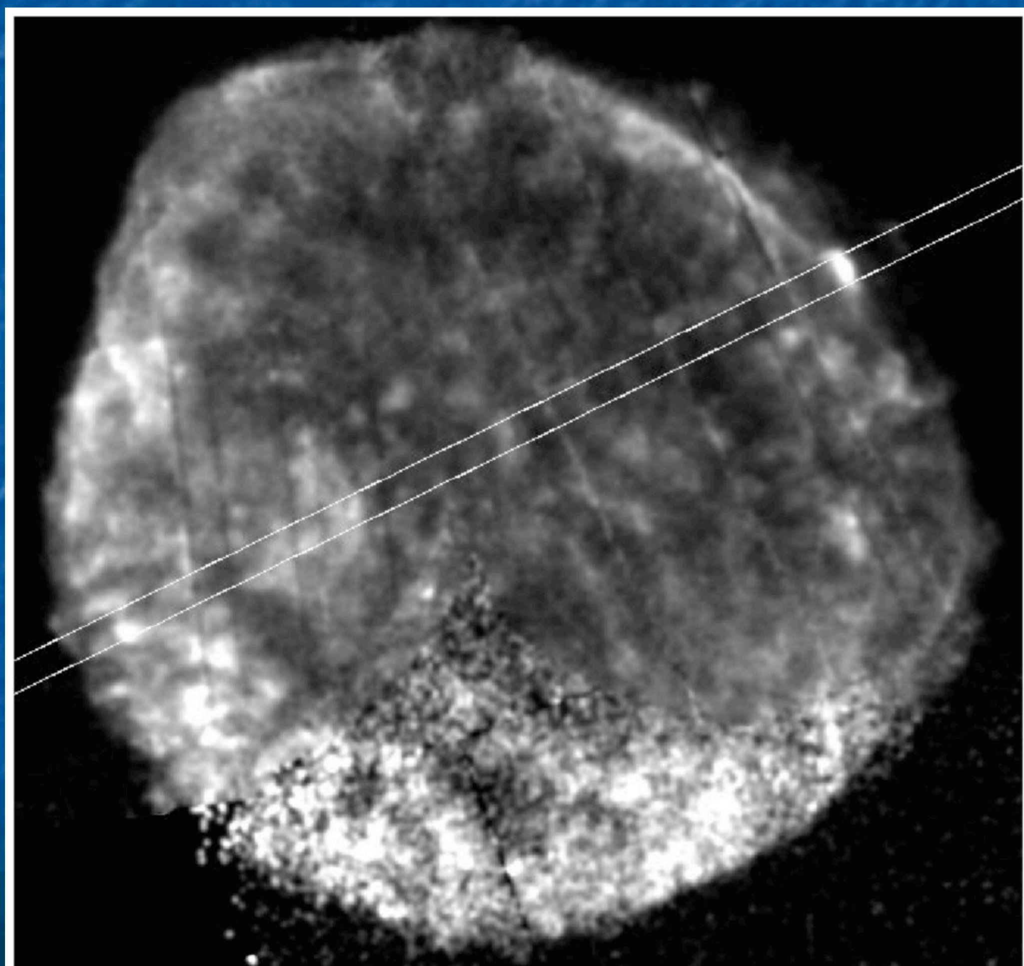


RGS spectrum fit with planar shock model and Doppler broadening

Kepler- XMM Results (Ballet 2002)

- Planar shock model with Doppler broadening:
- T = 0.54 KeV
- $N_H = 4.3 \times 10^{21}$
- Low abundances except for Si – contrary to expectations in a young SNR enriched by ejecta
- Best-fit velocity is 3000 km/s
- Imaging shows Si K and Fe L track each other, but oxygen emission is weak to the south

SN1006 with RGS (Vink et al 2003)



30’ diameter SNR

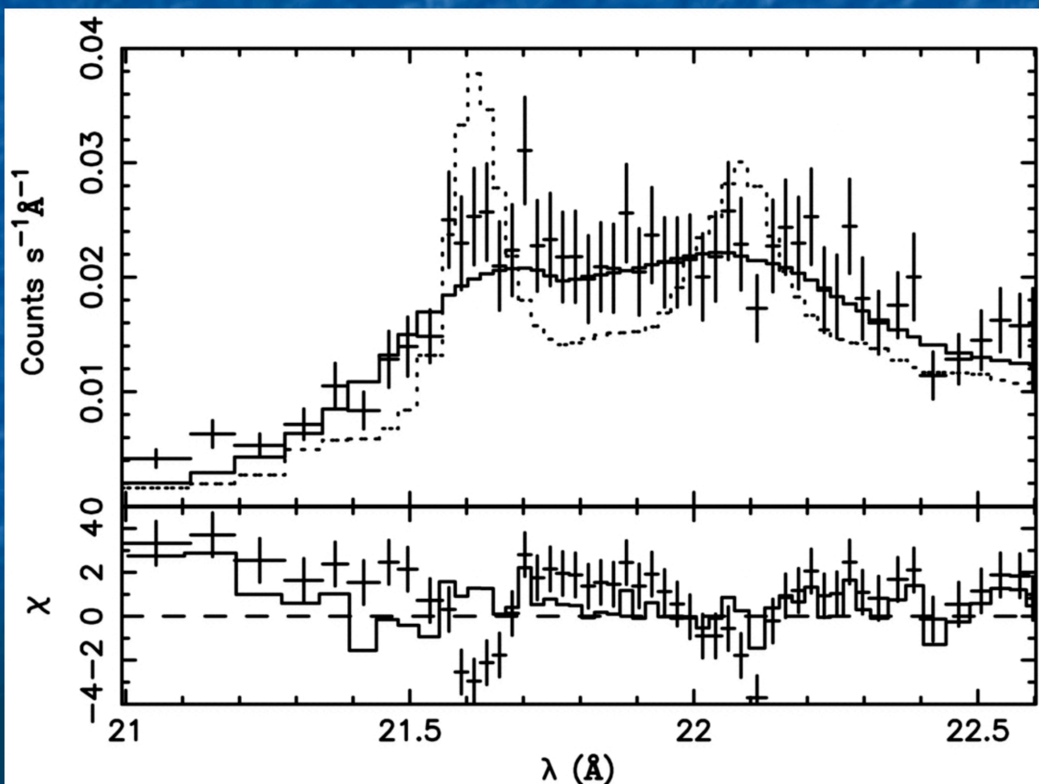
RGS High resolution spectrum of 0.4’ knot at NW edge

SN1006 with RGS (Vink et al 2003)

Measured Te with EPIC CCD spectra:

kTe = 1.3-1.7 keV

Fitted RGS spectrum from 21.0-22.3 A



Line broadening is required for acceptable fit, corresponding to kT_{oxygen}=530+/-150 keV

$kT_e \ll kT_{oxygen}$

Slow equilibration of electrons and ions in NW of SN1006

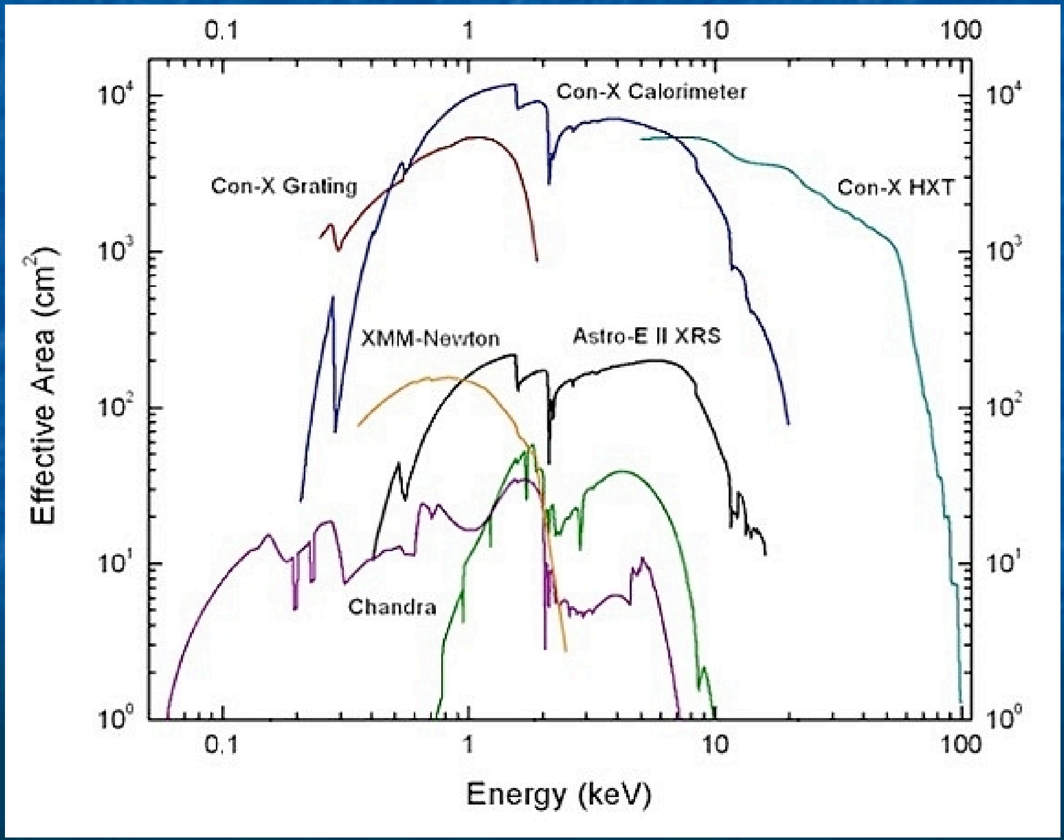
Looking to the Future: Con-X

- What are pertinent SNR issues ?

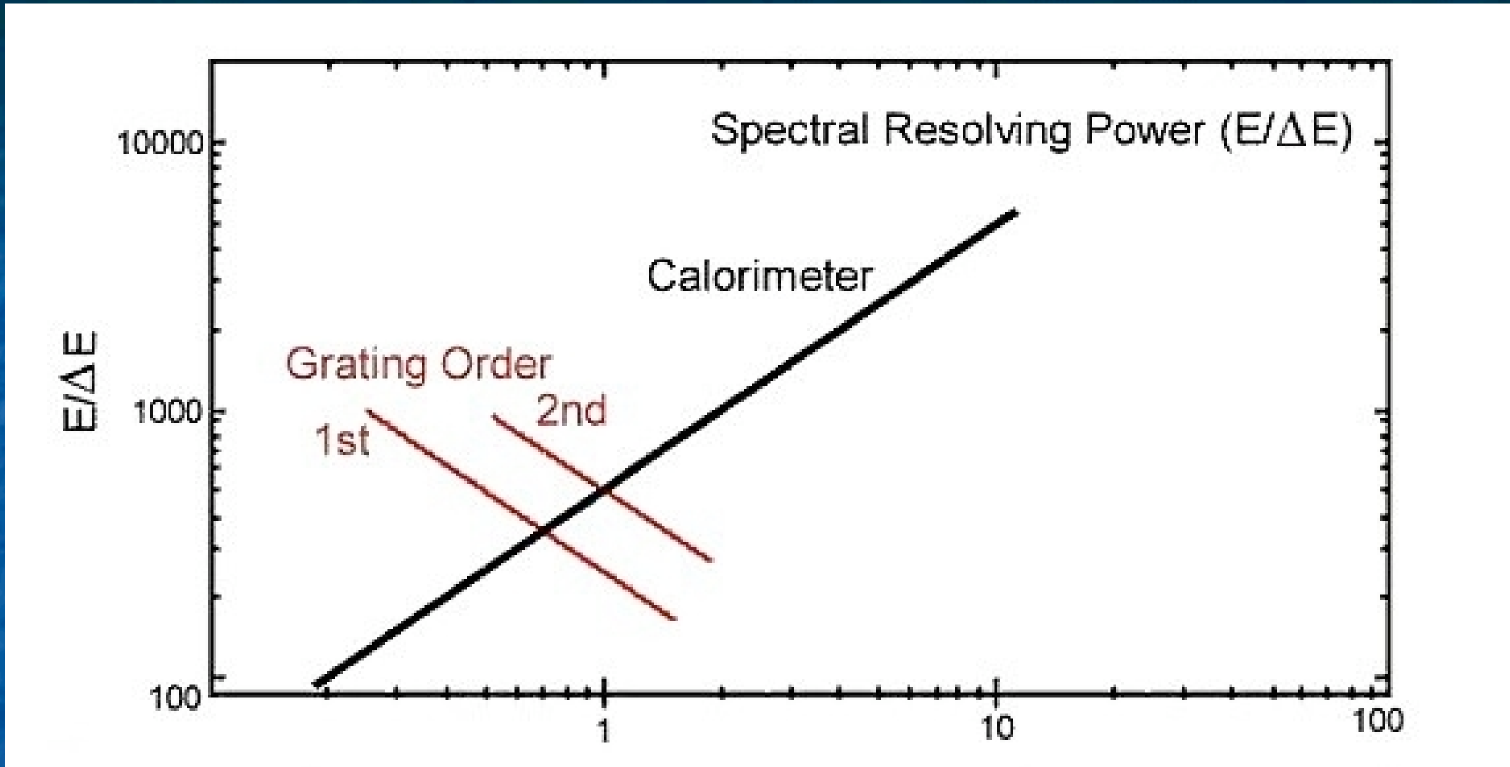
- Calorimeter will provide ***imaging*** high resolution spectroscopy above ~1 keV

(Images of extended sources as with today’ s CCDs, high resolution spectra as with today’s gratings, without the accompanying analysis headaches!)

ν High effective area will make more SNRs “accessible”. The calorimeter has ~10 times the effective area (at 1.25 keV) as the XMM CCDs, so we can expect high resolution spectra from CCD candidates*. Con-X gratings also have a factor of 10 increase over XMM gratings. More candidates – “see fainter, see farther, see faster.”

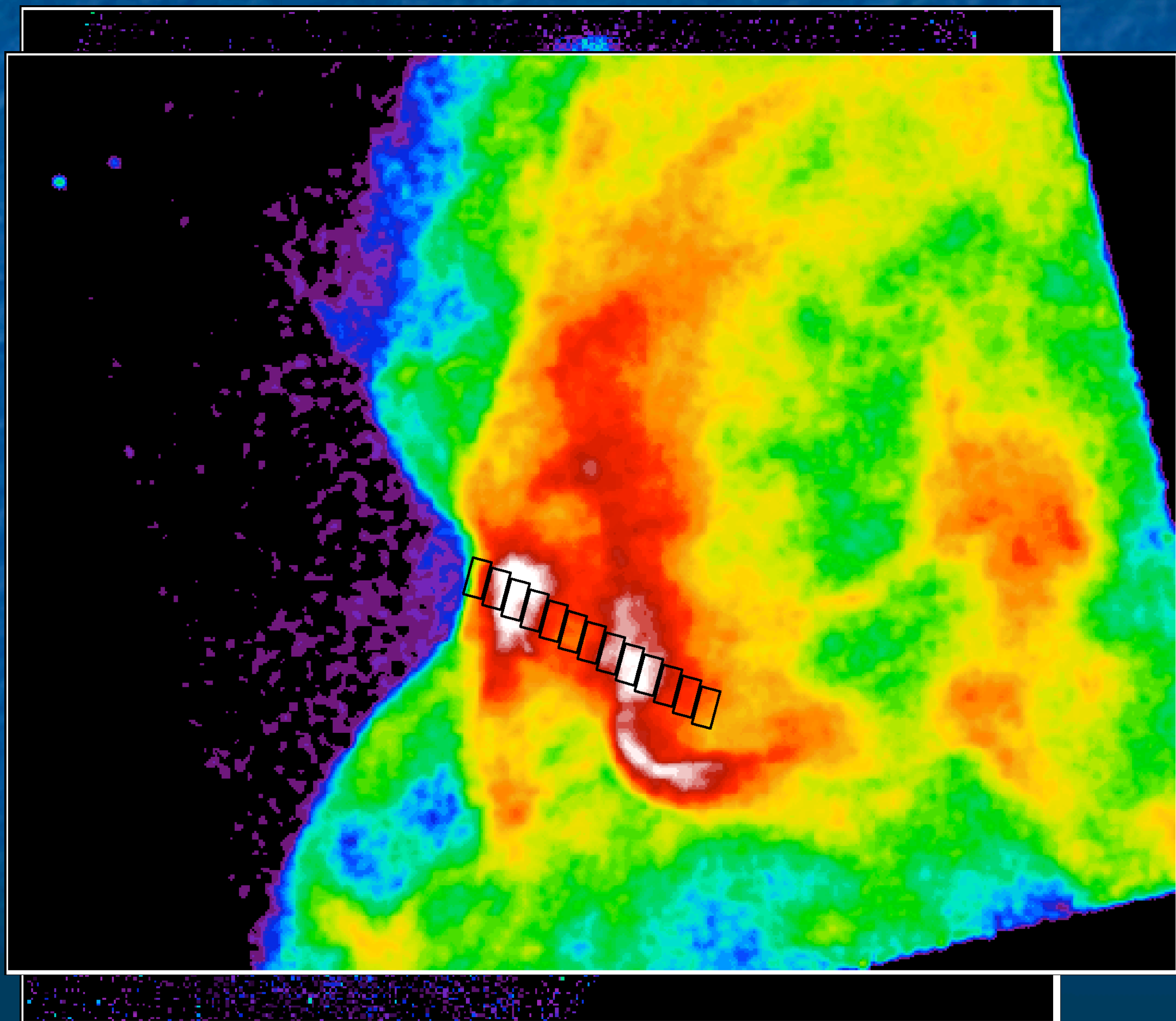


***Patnaude & Fesen 2203 report a 29 ks Chandra CCD observation of a SNR in NGC4449 … at ~4Mpc!!!**



- O and Ne lines (0.5 to 1 keV) are crucial to understanding SNRs – so high ***grating*** performance is essential. The calorimeter cannot substitute. $E/\Delta E \sim 1/\Delta\theta$, so that improved spatial resolution directly impacts spectral resolving power of gratings.

Why does spatial resolution matter?



Puppis A spectrum varies on 10” scales

Interpretation of the spectrum depends on size of the sampled region

Con-X and SNRs:

- Calorimeter will provide ***imaging*** high resolution spectroscopy above ~1keV
- High effective area will make more SNRs "accessible" for high resolution spectra.
- O and Ne (0.5 to 1 keV) are crucial to understanding SNRs – so high ***grating*** performance remains essential
- Spatial resolution affects our interpretation of the plasma, and directly influences $E/\Delta E$.